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Cover illustration: Thin sections of several different habits of barite. Photographs: Jane Clarke.

Botryoidal barite Mag 538; ppl.	Acicular barite Mag 549; xpl.	Poikilotopic barite Mag 530; xpl.
Bladed barite (white) Mag 580; ppl.	Botryoidal barite Mag 538; xpl	Spherulitic barite Mag 584; xpl.
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The Geoff Brown Memorial Lecture 2000: The Earth's temperature

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Everyone has some interest in the Earth's temperature, whether it's simply keeping an eye on the weekend weather forecast or day-dreaming about the ideal holiday destination. Nowadays, virtually all scientific disciplines are contributing to studies of the Earth's surface temperature because of the need to understand global warming and climate change. Earth scientists are also interested in the temperatures inside the Earth. Indeed the Earth can be thought of as a machine that runs on heat energy, and Geoff Brown was one Earth scientist who had a firm interest in understanding the Earth's energy budget, the sources of its internal heat and the way geological processes transport heat or are driven by heat energy. As this talk is being presented at Shap Wells it is also appropriate to remember that the nearby Shap granite was one of the intrusions Geoff studied in order to survey the abundance of heat producing elements (K, U and Th) in British granites and their contribution to surface heat fluxes.

My reasons for choosing 'The Earth's Temperature' as the topic for the 2000 Geoff Brown Lecture include the links to Geoff's research and his 'view' of Earth as a geologically active planet fuelled by heat energy. A further reason is my own fascination with the scientific detective work that can be used to measure temperatures across the face of the Earth, at locations deep within the Earth and at points in time far removed from the present. I have also become interested in the idea that very large volcanic eruptions can cool the Earth's surface. Here I will discuss just a few choice topics. The first of these is the illustration of some of the ways that temperatures deep inside the Earth can be estimated and how the results provide a picture of the Earth's dynamic interior and its cooling history. Second, I will show how temperature gradients, measured via boreholes inside the Earth, retain information about fairly recent changes to temperatures at the surface. Continuing the subject of surface temperature change, the third topic is some on-going work on the possible links between volcanism and short-term climate change.

The Earth as a hot rock

Geologists are adept at using clues in rocks and fossils to interpret the conditions or processes that formed particular parts of the Earth. What clues are available for telling us information about temperatures inside the Earth? While the ancients knew that the Earth's interior was hotter than its surface, and speculated on why this might be (see Sigurdsson 1999), the earliest measurements of the temperature inside the Earth were made during the 19th century in mines and boreholes. These and later measurements showed that the temperature increases by about 20 to 30°C for every kilometre down from the surface. To give a modern example, in 1994 the German Continental Deep Drilling Program (KTB) completed a 9.1km deep borehole in SE Germany and measured a bottom temperature of about 260°C and a temperature gradient of roughly 27.5°C km^{-1} (Haak & Jones 1997). One may ask what the value of such results is. After all, this is one of the deepest holes drilled and yet only scratches the surface of the Earth. One of the key results from this and very many shallower boreholes is that the rate of heat energy flowing to the Earth's surface can be estimated from the temperature gradient multiplied by the thermal conductivity of the drilled rocks. The steeper the geothermal gradient, the greater the heat flow. The present day total global surface heat flow is 4.4×10^{13}W and is a key piece of information for any model of the Earth's internal evolution. Explaining why it is this and not some other value involves having to consider the processes by which the Earth cools.

At this moment we can recall a famous piece of scientific detective work. Just as the Lone Ranger could feel the warmth in a campfire's dying embers and quote the time since the retreating baddies had extinguished the fire and broken camp, can we work back to the Earth's fiery birthdate given a measurement of how cool the surface is now? The first attempt to work out the Earth's age from its present cooling rate was done by the eminent physicist Lord Kelvin in the 1860s. He had measured the temperature gradient in some mines near Edinburgh (getting a rather high value of about 35°C km^{-1}), decided that the Earth was initially molten and reckoned that the melting temperature of rock was 3,900°C. Starting with an Earth at 3,900°C throughout, and keeping the surface at a steady 0°C, heat would flow from the interior and be lost to space. As cooling progressed, the temperature gradient just below the surface would get less and less as cooling penetrated into the Earth. Kelvin had obtained measurements of the rate at which heat moved through rocks (a thermal diffusivity of about 1.18×10^{-6} m^2 s^{-1}) and this allowed him to calculate the time taken for the Earth to attain the surface temperature gradient that he had measured. His answer for the age of the Earth was about 100 million years, but when better estimates of the melting temperature of rocks (1200°C) became available he recalculated the age as around 20 to 40Ma.

As many Victorian geologists had suspected, Kelvin was wrong; the age of the Earth is about 4,500Ma, a hundred times older than he had calculated. We can still use his reasoning in a different way, though. Given an age of 4,500Ma, what is the initial temperature of the Earth? A surface gradient of 35°C km^{-1} requires an initial temperature of 25,400°C and a gradient of 20°C km^{-1} requires 14,500°C. These are unreasonably high and, furthermore, most of the Earth would still be at the initial temperature. Rather than trying to resolve these problems by debating any flaws in Kelvin's logic, is it possible to find new information about the temperatures inside the Earth?

Measuring the temperature of the Earth's interior

In Kelvin's time little was known about the Earth's internal layering, and techniques for deducing internal temperatures that Earth scientists now take for granted were non-existent or were incapable of being applied. Among these are the following:

1) Minerals as thermometers and barometers

In general, the chemical compositions of minerals that form under conditions of chemical equilibrium in a rock depend on the temperature and pressure of equilibration. Some minerals are more sensitive to temperature (so are called geothermometers) and others are more sensitive to pressure (geobarometers). Suitable geothermometers and geobarometers are present in garnet-bearing mantle peridotites brought to the surface as xenoliths in certain

volcanic eruptions, allowing the temperature and temperature gradient in the upper mantle to be found. For example, the chromium (Cr) and enstatite ($Mg_2Si_2O_6$) contents of clinopyroxenes coexisting with garnet have been used to find that temperatures in the mantle beneath continental cratons change from about 550°C at 65km depth to 1,400°C at 200km depth (Nimis & Taylor 2000). The results are also consistent with whether graphite (stable at low pressure and temperature) or diamond (stable at high pressure and temperature) were present in the samples.

2) Conditions for magma genesis at mid-ocean ridges

Basaltic crust is produced at mid-ocean ridges by partial melting of hot mantle as it undergoes decompression beneath the zone of sea-floor spreading. Because the solidus temperature of peridotite increases with pressure, it follows that the hotter the decompressing mantle then the greater the amount of melting and the thicker will be the resultant oceanic crust. The thickness of oceanic crust therefore depends on the temperature of the mantle and is, in effect, a 'thermometer' for the upper mantle beneath ocean lithosphere.

The average thickness of ocean crust is 7km, which requires that the mantle beneath mid-ocean ridges has a potential temperature of 1,280°C. The potential temperature is actually the temperature mantle material would have if it was brought from high pressure to the surface without losing any energy, so the actual temperatures in the sub-lithospheric mantle are somewhat higher.

3) Core structure

Seismic studies and ideas about planetary interiors deduced from meteorites have established that the Earth's core is metallic (largely iron) and that the outer core is molten whereas the inner core is solid. The temperature at the outer core/inner core boundary, at a depth of 5,124 km and a pressure of 330GPa (3.3 million atmospheres) must therefore be the melting temperature of iron (with some impurities) at 330GPa. But finding what this temperature is by doing experiments at such extreme conditions is by no means simple! One technique involves compressing a sample of iron between tiny faces of diamond that are pressed together under enormous force to achieve the very high pressure. At the same time, a laser is fired at the compressed sample of iron to raise the temperature enough for it to melt. The current best estimate of the temperature at the inner core/outer core boundary, from experiments and theoretical calculations, is 6,400 ± 600°C.

4) Hot spots

Volcanoes in the middle of plates are explained by the presence of unusually hot (and therefore buoyant) mantle rising from deep in the Earth and melting as it nears the surface. These plumes of hot mantle are characteristic of convection in a very viscous material (like hot mantle rock) when it is heated from below. In the case of the mantle, heat from the core warms the base of the mantle. Over time the heated layer, or thermal boundary layer, at the base of the mantle becomes thicker until it becomes sufficiently hot and buoyant to become unstable and rise as a hot thermal plume through the mantle. Hot spot volcanoes are the expression of the intermittent production of such plumes at thermal boundary layers in the mantle (such as at the core/mantle boundary).

Thermal structure of the Earth's interior

We have seen that there are a range of techniques for determining the temperature at various places within the Earth and also that the existence of hot spots indicates that the Earth's mantle is convecting. This gives us information about the Earth's temperature in regions far beyond the reach of instruments lowered down mines or boreholes. Seismic studies also show that the seismic wave speeds in the mantle are slightly heterogeneous, an observation that can be explained if the temperature distribution is not homogeneous but is stirred by convection currents. A picture derived from the assembled information is given in Figure 1, showing steep temperature gradients in thermal boundary layers and convection in the mantle taking place in broad cells and in narrow plumes. Convection also occurs in the liquid outer core. The temperature distribution is very different from the one envisaged by Kelvin, who assumed that the Earth was cooling by conduction only and was uniformly hot below the surface layers. He had also been unaware of the existence of radioactivity and that isotopes of U, Th and K were producing heat by radioactive decay in the Earth, acting to replenish some of the heat lost to the surface. Critically, however, it is the influence of convection on the temperature distribution and cooling rate of a layered Earth that largely explains Kelvin's underestimation of the Earth's age (Richter 1986).

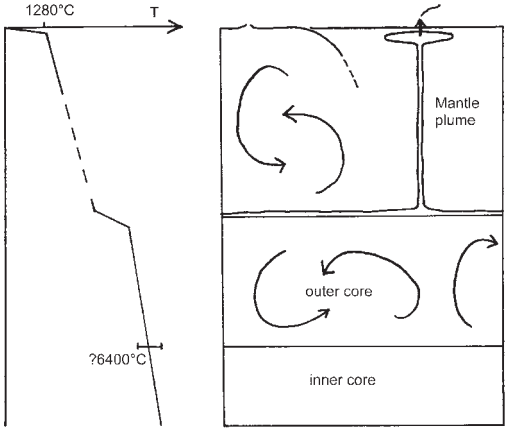

Figure 1. A sketch of the Earth's internal structure and temperature distribution. Important features are the convecting nature of the mantle and outer core, the large temperature drop (several hundred degrees Celsius) across the thermal boundary layer at the core/mantle boundary, mantle plumes rising from the thermal boundary layer, and the motion of cold lithospheric plates across and into the Earth.

How fast is the mantle cooling?

We can reflect that Kelvin was interested in using measurements of Earth's heat loss and assumptions about how heat moves in the Earth in order to calculate the age of the Earth. Today, Earth scientists have turned this approach around and are interested in using the known age of the Earth together with measurements of Earth's heat loss and temperature distribution to learn how heat moves inside the Earth, how quickly the planet is cooling and the growth rate and history of the inner core. The recently published advanced text book by Geoff Davies (1999) provides an overview of this approach. To pick just one example, let us consider how quickly the mantle is cooling.

The mantle loses heat to the crust but also gains it from radioactive decay and cooling of the core. The rate at which heat leaves

the mantle is found by taking the rate at which heat reaches the surface and subtracting the rate at which radiogenic heat is produced in the crust. This amounts to 36 x 10^{12}W. Estimates of the abundance of heat-producing isotopes in the mantle lead to an estimate of radiogenic heating of 23 x 10^{12}W. The amount of heat carried into the mantle in plumes escaping from the core/mantle boundary is estimated as about 3.5 x 10^{12}W. Overall, the loss outweighs the gains, and the mantle loses heat at a rate of some 9.5 x 10^{12}W. Converting this to an average rate of temperature change for the whole mantle using the principle that the cooling rate = power output/(mass of the mantle x specific heat capacity of mantle materials) gives an estimated rate of 75°C per billion years. Such a slow cooling rate suggests that the viscosity of the mantle (a strong function of temperature) has not changed dramatically over recent geological time. Consequently, the present remains the key to the past (at least for the vigour of interior processes throughout the Phanerozoic!).

Measuring surface temperature changes inside the Earth

The Earth's surface temperature has been reliably measured for several centuries, but only at a few places. More even coverage, sufficient to give global average temperatures, is a more recent development and meteorologists are now confident in global mean surface temperature data for each year since 1856. The mean temperature is currently about 15°C, but the data are conventionally reported as a deviation from the mean value of a 30 year reference period. Figure 2 shows the global temperature anomaly relative to the 1961 to 1990 mean and reveals a trend of global warming which society is now challenged with understanding in order to predict or mitigate its development. The detection and quantification of a warming trend is made tricky by the relative shortness of the instrumental record, so ways need to be found of estimating surface temperatures from historical descriptions of climatically-sensitive phenomena (Lamb 1995) or chemical, biological or fossil evidence tied to precise dating (see for example the books by Alley (2000) and Bradley (1999)). Intriguingly, however, subsurface temperatures measured in boreholes can also be used to decode the surface temperature of the past (Pollack & Chapman 1993).

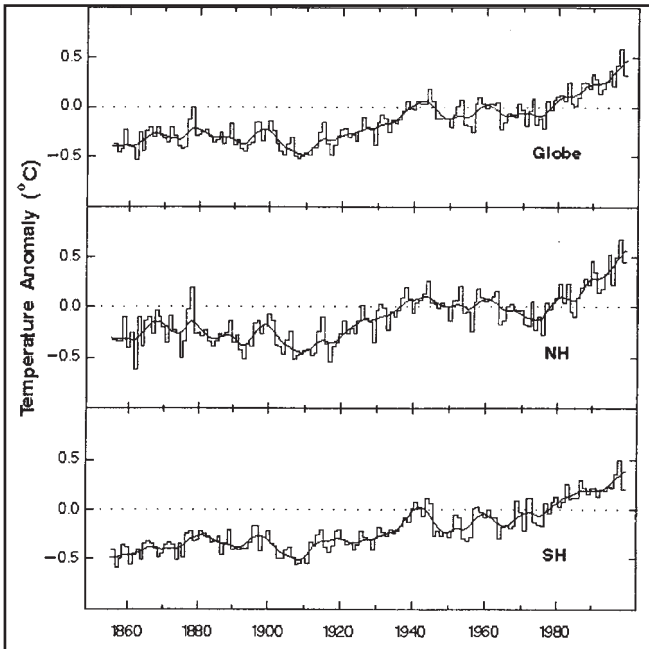

Figure 2 Global and hemispheric annual mean temperature anomalies relative to the mean of 1961 to 1990.
(http://cdiac.esd.ornl.gov/trends/temp/jonescru/graphics/nhshglob.gif)

To see how this works, imagine that you take a metal rod and hold it in a fire. Heat travels up the rod, eventually reaching your hand. The longer the rod, the longer you have to wait to feel the warm signal conducted from the fire. Also, the temperature rise at a given distance along the rod (after a particular amount of time) depends on the temperature at the heated end. The Earth's shallow rocks behave in just the same way, with any warming (or cooling) of the ground surface penetrating down into the ground. The daily cycle of warming and cooling propagates no more than a metre and seasonal changes penetrate a few metres (the best depth for wine cellars!) but changes that last for centuries alter the temperature in the top 150m. For example, the temperatures in the upper part of the borehole (beneath a thin very shallow disturbed layer) shown in Figure 3 are higher than expected from the extrapolated geotherm (dashed line). The explanation is that the Earth's surface has been warming up, with the duration having been sufficient for the warmth to have penetrated a hundred metres or so. The warming needed to produce the observed measurements in this and other boreholes in the same area is about a 1.5°C rise over the past 300 years. The average value for data including a large proportion of the continents is about 1.0°C warming over the past 500 years, but with 0.5°C of this having taken place in the 20th century (Huang *et al.* 2000).

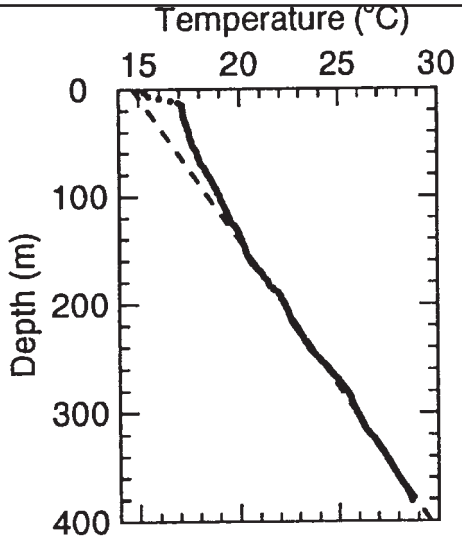

Figure 3. Elevated temperatures in the uppermost section of a 400m deep borehole in Oklahoma, USA, reveal recent warming of the Earth's surface (from Deming & Borel 1995).

Surface temperatures and volcanic eruptions

The Earth's surface temperature is influenced by many factors. Warming is enhanced by the greenhouse effect due to CO_2, H_2O and other gases in the atmosphere trapping solar energy in the lower atmosphere. The causes of surface warming such as seen in Figures 2 and 3 is the subject of much debate, with a strong link between warming and increased atmospheric concentration of certain greenhouse gases (especially CO_2) being taken to imply that anthropogenic CO_2 emissions have led to warming. A reduction in greenhouse gases would be expected to lead to cooling, as would a decrease in the amount of solar radiation reaching the Earth's surface.

For some time anecdotal and some instrumental data have been used to support a link between large explosive volcanic eruptions and a slight cooling of the Earth's surface temperature on global or hemispheric scales. For example, following the 1991 eruption of Pinatubo, Philippines, the northern hemisphere mean global temperature appears to have temporarily fallen, although the record is noisy and therefore difficult to interpret (Figure 4). The Pinatubo eruption led to some spectacular optical effects, such as lurid sunsets, due to tiny solid and liquid particles injected into the upper atmosphere (the stratosphere) by the eruption. The longest-lasting particles are liquid droplets of sulphuric acid less than one micrometre across formed by chemical reactions between SO_2 gas released from the erupting magma and the atmosphere. Such gases get removed from the lower atmosphere by rain but no such efficient mechanism exists in the stratosphere, so these particles are removed slowly, on a time scale of many months to a couple of years. This is long enough for the aerosol particles to be dispersed in the stratosphere encircling the globe, or at least part of one hemisphere, with a turbid cloud thick enough to cut out some solar radiation, potentially causing surface cooling. The amount and lifetime of the aerosols will influence the amount and duration of any surface cooling resulting from them. The question then arises as to whether the amount of cooling after a volcanic eruption bears any relation to the size of the eruption.

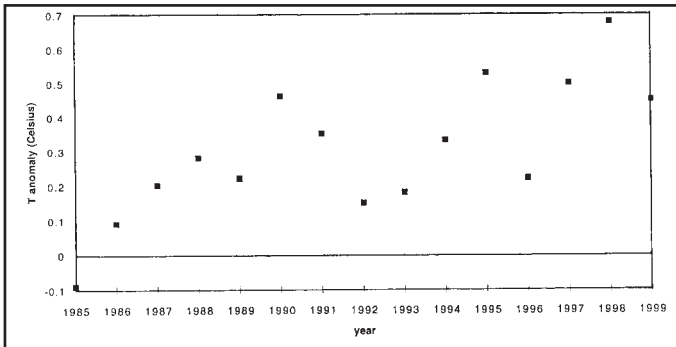

Figure 4. Northern hemisphere mean annual temperature anomalies relative to the mean value for 1961 to 1990. (http://cdiac.esd.ornl.gov/trends/temp/jonescru/graphics/nh.dat)

Only eruptions that lift gas and ash into the stratosphere are relevant to this mechanism and these are relatively rare, about one per year, but with the largest eruptions being the rarest; for instance the Pinatubo 1991 eruption (5km^3 of magma, 20 megatonnes of SO_2) was a roughly 'once in 50 to 100 year event'. With instrumental records not extending far back in time (Figure 2), the possibilities for correlating amount of cooling with eruption size are severely limited. Again, we must use our ingenuity to find information about temperatures in years for which there are no instrumental data, for example by using the record of a tree's environment preserved by the characteristics of its annual growth rings. One such characteristic is the density of the wood which correlates strongly with mean summer temperature. Potentially, there is a year by year record of summer temperature extending back to the oldest dated tree rings and we can look for any cooling effect of large eruptions that happened before instrumental temperature measurements were made. Tree-ring specialists have already done this (e.g., Briffa *et al*. 1998) and found that anomalously cold summers in the Northern Hemisphere typically follow large eruptions. Given that the mass (or volume) of erupted magma is roughly proportional to the mass of SO_2 gas injected into the atmosphere, I have compared the size of eruptions (by the mass or volume of magma erupted into the stratosphere) with the amount of cooling implied by the size of the tree-ring anomaly. Eruptions of less than about 2km^3 of magma did not cause a detectable cooling effect. Seven eruptions larger than this preceded cooling of up to *ca.* 0.8°C. None of these eruptions produced more than 50km^3 of magma, so the effects of a truly enormous 'super eruption' such as the 3,000km^3 eruption of Toba caldera, Indonesia, about 74 thousand years ago cannot be extrapolated from the currently available data. While meteorological computer models predict that aerosols from Toba may have persisted for up to a decade, the challenge still remains to find palaeoclimate data for the exact years before and after this eruption.

Conclusions

Geologists need all the clues they can get in order to make sense of the Earth. Because cooling of the Earth's interior and solar heating of the surface drive most geological processes, such clues include the temperature distribution within and around the Earth, at the present and in the past.

The examples I have chosen illustrate some of the clever techniques for measuring the temperatures of places that are separated from us by great distance or by great amounts of time. Such 'inaccessible temperatures' (to imitate the title of a book by Geoff Brown & Alan Mussett (1981)) provide information about the evolution of the Earth's interior and of the conditions over its surface.

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Almost Hidden and Forgotten

Gladys Dinnacombe BPhil (Open)

When I first moved to Kettering, it was hard to imagine that this quiet market town could once have been part of the busy, industrial, noisy ironstone scene. Less than 100 years ago, the area was criss-crossed by railway lines used by steam engines hauling limestone and ironstone to other parts of England. The dust and the noise must have been incredible especially when British Steel had furnaces in nearby Corby. But what is left to remind us of this time? Research in the local library and Museum produced books to read, mainly about the railways in the quarries. There were BGS survey reports too, although now out-of-date. But are there any old quarry sites with rock faces to inspect still around? A detailed study of local maps proved successful and a visit to the Rockingham Forest Trust also gave many clues. But first, a brief review of the geology in this area (Figure 1).

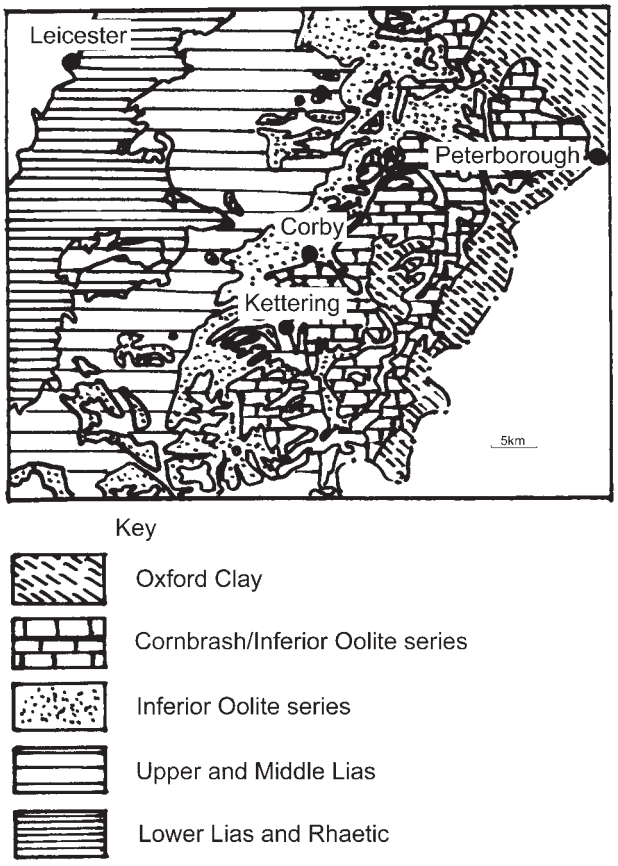

Figure 1. Sketch map of the geology of the area (after Hains 1969).

Jurassic rocks outcrop in this part of Northamptonshire, the ironstone being part of the Northampton Sand Ironstone formation, which itself is part of the Inferior Oolite Series (Table 1).

At the end of the Lias, there was a gradual uplift of the land, causing the seas to become shallower and the environment to change from a deep-sea to an off-shore environment. Rivers from the higher ground brought sediments to the shallow sea and formed the Northampton Sand Formation.

The sequence represents 3 phases of sedimentation, one in which carbonates predominate, one in which both carbonates and alumino-silicates are present and one which comprises only alumino-silicates. Throughout the succession, sea-bottom conditions have controlled the nature of the iron-bearing constituents.

Table 1: Stratigraphic column for the area

Jurassic
Oxford Clay and Kellaway Beds: Oxford Clay Kellaway Sand Kellaway Clay
Great Oolite Series (now known as the Rutland Formation): Cornbrash Blisworth Clay Blisworth Limestone Upper Estuarine Series/Rutland Formation
Inferior Oolite Series (now known as the Grantham Formation): Lincolnshire Limestone with Collyweston Slate Lower Estuarine Series/Grantham Formation Northampton Sand Ironstone
Lias: Upper Lias Middle Lias Lower Lias

There are five sub-divisions within the Northampton Sand (BGS memoirs Hollingworth & Taylor 1951):

5. Upper Chamosite - Kaolinite Group
4. Upper Siderite Mudstone - Limestone Group
3. Lower Chamosite - Kaolinite Group
2. Main Oolitic Ironstone Group
1. Lower Siderite Mudstone - Limestone Group.

The sea continued to become shallower and became a coastal zone with lagoons, sandbanks and mudflats. These deposits are the Lower Estuarine Series/Grantham Formation and consist of silts, sands and clays. In this area the Lower Estuarine Series/Grantham Formation is followed by the Upper Estuarine Series/Rutland Formation in which clays predominate. Occasionally during this time, the sea deepened and beds of sand and shelly marls as well as a bed of limestone were deposited. The clays above and below the limestone are filled with oyster shells. As the sea deepened again new sediments, the Great Oolite Series, were formed. These are mainly limestones, some beds being full of *Kallirhynchia sharpi* whilst others are full of oyster shells. The Blisworth Limestone and the Blisworth Clay are part of the Great Oolite Series. The clay is often strongly coloured.

My first visit was to the nearby village of Geddington (Figure 2), where according to the OS map there were disused pits with public footpaths running close by. The first lease for the pits, known as Geddington Quarries for the first part of their lives, was granted by the Duke of Buccleuch in 1897 although there is little known about the working of these quarries until 1902. There were 4 main pits/quarries and their output went to the furnaces at Bennerley in Derbyshire. At this time all the overburden and the ore was removed by hand.

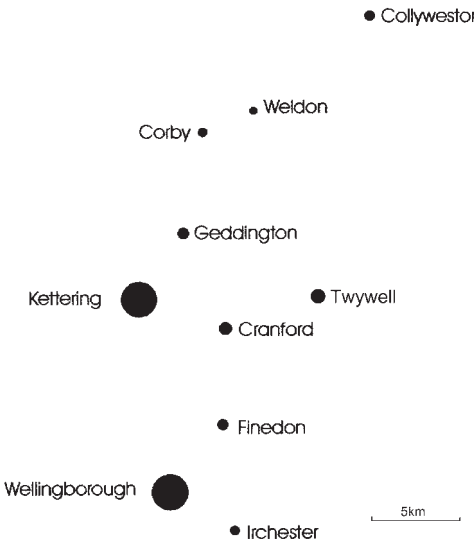

Figure 2. Sketch map to show location of towns and villages.

As the quarries were so far from the village the owner had cottages built for the workmen and these can still be seen today. In 1930 the quarries became known as Storefield Quarries. Today much of the quarried land is half-filled in but has been planted with trees. It is still obvious that quarrying went on here from the way the land is 'up and down', forming miniature hills where the overburden had been piled. The old railway track beds form useful paths for exploration. The woods by Geddington/Storefield quarries have many public paths through them but there is very little left to see of the geology. However, in one part the path comes upon a very deep pit filled with water and a small part of an exposed quarry face which is accessible. Here the ironstone can be seen clearly forming a square box-like structure (Figure 3). The 'box structure' is produced by a redistribution of the iron oxide in the rock so that it is concentrated in the dark layers and removed from the pale layers. This occurs when the ironstone is weathered and is heavily oxidised to limonite and goethite.

Figure 3. Ironstone at Geddington Quarries.

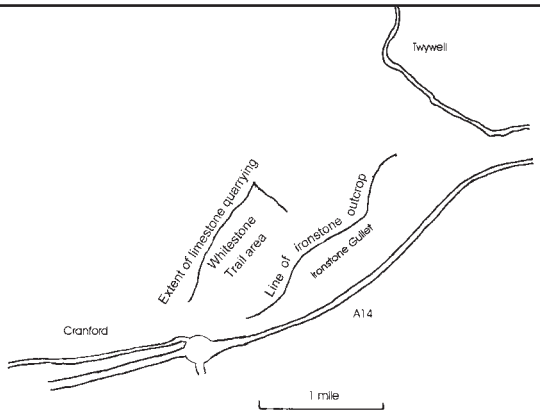

Figure 4. Twywell area showing limestone and ironstone areas.

Layers, parallel to the joints, alternately richer and poorer in ferric oxide, are laid down to form the 'box' structure. During this process fossils are more or less destroyed. The iron in the ores was formed by complex chemical reactions in the sea.

The quarries were worked until 1973 when the railway track was removed and the buildings demolished. Most of the quarries were partly infilled and planted with larch, acacia, poplar, sycamore, oak, spruce, hornbeam and other trees, in what is known here as 'hill and dale' style. This emphasis on afforestation was the policy of the Boughton Estates Ltd, the owners of the land, and they preferred to plant trees which were most suited to the sites.

My next visit was to Twywell (Figure 2) where there is more information as the site has been bought by East Northamptonshire Council for conservation and recreational opportunities. It is managed by the Rockingham Forest Trust who have produced several leaflets about this area and the quarrying. Quarrying did not begin at Twywell until 1920 but again the stone was removed by hand and not machine. The stone was smelted at nearby Islip while the narrow gauge railway line became part of the largest narrow gauge railway system in the country. There were both limestone and ironstone quarries and it is possible to access both areas through the site now managed by the Rockingham Forest Trust (Figure 4). The ironstone site known as the Gullet is a designated Site of Scientific Interest because of its rich wild life. The wood which covers a large part of the area was planted after extraction finished and is mainly of European larch. More trees have been planted since then. The quarry closed in 1948.

These stratigraphical details (Table 2) are taken from the BGS geological memoirs to the Kettering geological sheet (Taylor 1963) and give a picture of what could be seen when quarrying was in operation.

The Northampton Sand is generally yellow or orange-brown and is ferruginous; it can be seen in many local buildings. The basal beds of the Northampton Sand are more iron-rich and form the Northampton Sand Ironstone. The worked ore bed varies in depth from 4 to 12 feet and is dark brown, grey or green sandstone in massive blocks and also in thinner beds. The bottom and top layers were too low in iron content or too sandy to be economically workable.

Parts of the bed show a 'box structure' which is explained earlier. Some of the rock is oolitic. The analysis of the ore in this area is as given in Table 3.

Table 2. Stratigraphic column for Kettering

Great Oolite:	
Soft white shelly oolite limestone with oyster marl at base	2′ 3"
Massive shelly detrital limestone, finely laminated	10"
'Epithyris' bed - soft white limestone	9"
Massive shelly detrital limestone	8"
Soft white sparsely oolitic shelly limestone with marly partings	1′ 10"
'Trigonia' bed - massive limestone	9"
Pale brown massive fine-grained limestone	1′ 8"
Very rubbly white oyster limestone	1′ 0"
Grey and brown clay with '*Kallirhynchia sharpi*'	4"
Fine-grained white argillaceous limestone	10"
Grey and brown clay with '*Kallirhynchia sharpi*'	6"
Fine-grained white argillaceous limestone with var. fauna	8"
Upper Estuarine Series:	
Grey and brown silty marls	2′ 6"
Grey clay (with extensive fauna)	2′ 4"
Impersistent nodular limestone	3"
Hard silty limestone with pockets of shelly clay (ext. fauna)	4′ 0"
Grey shelly silty clay (ext. fauna)	10"
Brown clay	7"
Grey silty clay with shell fragments	1′ 8"
Greenish grey clay	1′ 0"
Dark grey clay	1′ 0"
Lower Estuarine: 'Ganister'	
Northampton Sand:	
Siderite mudstone	2′ 4"
Oolitic ironstone (with shelly band)	7′ 10"
Siderite mudstone	8"

Table 3.
Twywell Ironstone Pit average of 6 samples (dried) 9 ft. bed

Fe	42.3%
SiO_2	12.4%
Al_2O_3	6.3%%
CaO	2.1%
Loss on calcination	15.7%
Moisture	- -
S	0.277%

The old limestone quarry, now part of the Whitestone Trail (Figure 4), has been mainly left in the 'hill and dale' manner with scrubby bushes growing here and there. The trail passes several small outcrops (Figure 5) of Great Oolite Limestone/Blisworth Limestone; rubbly detrital skeletal limestone with many partings and also an occasional section showing a massive white detrital limestone with some current bedding. There are more exposures off the path, some with much higher faces, but which were inaccessible at the time of my visit (early summer).

Figure 5. Exposure of Great Oolite Limestone / Blisworth Limestone on the Whitestone Trail.

As late as the 1940s the loading of limestone was still done entirely by hand. The soil was taken from the top, the limestone blasted and the lumps then loaded onto waiting wagons. The limestone was needed to help separate out the iron at the furnace in Islip and was transported on the narrow gauge railway. The limestone analysis is given in Table 4.

Table 4. Analysis of Great Oolite Limestone:

SiO_2	5.1%
Al_2O_3+ Fe_2O_3	4.0%
CaO	49.7%
MgO	0.6%
S	0.245%
Loss on ignition	39.8%
Moisture	2.7%

At first the shallower beds of ironstone were worked by hand, using barrows to take away the soil. Machines enabled the deeper ironstone to be uncovered using the double digging process. One machine pulled out a 'gullet', and the transporter moved the soil to form a hill on parts that would not be excavated. The ironstone was then removed and a new gullet started, the topsoil/overburden from the new gullet being placed in the worked-out gullet. After being blasted out the ironstone was picked up by a 20 ton loading machine and loaded into the wagons to be taken to Islip on the narrow gauge railway.

At Islip furnaces iron was produced for casting in rough bars or 'pigs'. The furnaces were closed in 1942 and the limestone quarrying stopped soon after this in 1943 having been worked from 1917. Ironstone quarrying ceased here in January 1948.

The old ironstone pit, now part of The Gullet, also shows a few exposures of the ironstone (Figures 6 & 7) and also a few relics of the old railway track and haulage system. The ironstone is of the Upper Siderite Mudstone-Limestone Group.

As all the shallower beds were removed by hand in the early years of quarrying, the sites that were worked are now hardly noticeable. Those who know about this area, however, know where to look for clues! Most worked sites which are now back in use as pasture or for crop growing tend to lie much lower than the road and surrounding fields and woods.

Figure 6. Exposure of ironstone at the Gullet.

Figure 7. Exposure of ironstone at the Gullet.

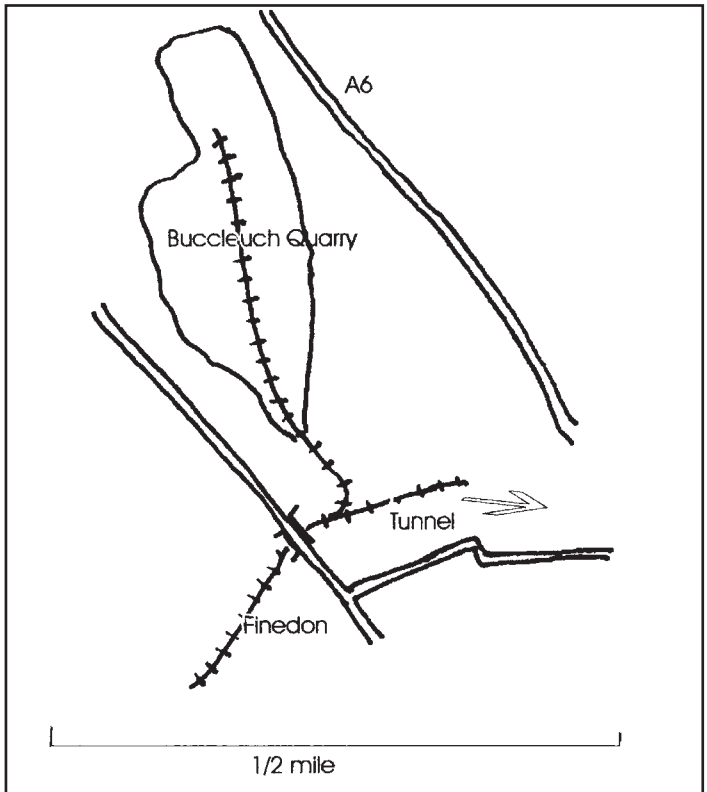

Figure 8. Sketch map showing the location of Buccleuch Quarry.

Figure 9. The upper beds of Blisworth Limestone in Buccleuch Quarry.

A search for a good limestone outcrop led me to Finedon (Figure 2). Finedon has a 'pocket park', one of the first of its kind, a small conservation area created in 1984. The Pocket Park Scheme is promoted by Northamptonshire County Council "to encourage the creation of countryside areas for use by its residents and to provide wildlife habitats where plants and animals flourish". It occupies the site of a former ironstone quarry and part of the railway line which connected the quarry to the ironworks at Wellingborough (Figure 8). The Ebbw Vale Co. acquired the land first, but it was their successors, Richard Thomas and Co Ltd., who developed the quarry, known as Buccleuch Quarry, in 1938, by driving a gullet northward from the Cricket Field Pit east of the Volta Tower. (The Volta Tower was a prominent local landmark built in memory of a member of the Dolben family of Finedon Hall who was lost at sea in the S.S.Volta. In 1951 the tower partially collapsed and was dismantled later in the 1950s.) The north-south working face extended for almost a mile and, although much of it is now covered in grass and scrub, there is a reasonable view of the upper strata towards the middle of the quarry. Much of the path through the quarry is along an ironstone bed. The beds in the upper strata are generally 'level' but there seem to be a few small faults trending E-W (Figure 9).

In Buccleuch Quarry the overburden was between 30 and 40 feet thick which had to be removed before the 10 foot ironstone bed could be worked. The upper part of the overburden was mainly Blisworth Limestone but in places was replaced by boulder clay. The upper part of the shelly oolite bed at the top of the main ironstone group was replaced by material resembling a fine breccia.

Figure 10. The remains of the crushing plant at Buccleuch Quarry.

Figure 11. Collyweston Slate at Collyweston.

Figure 12. Collyweston slates exposure showing erosion of softer sandy beds.

Until 1941 the stone was taken to Irthlingborough via a four mile tunnel. It is interesting to note that the tunnel, 'holed through' from both ends, was only 6 inches out of alignment. Some of the stonework of the bridges leading to the tunnel remain as well as parts of the crushing plant (Figure 10). In 1941 the quarry was linked by a direct line to the LMSR line to Wellingborough. The quarry closed in 1946 and although there were plans to reopen it at a later date this did not occur. All that remains of evidence of the working of the quarry are the concrete and wood sleepers of the railway track which now form the main path through the park, the remains of the concrete crushing plant and the upper strata of the quarry face.

Still searching, I visited an area where Collyweston Slates can be seen. Collyweston slates are the basal beds of the Lincolnshire Limestone and were mainly quarried at Collyweston, Easton and Duddington (Figure 2). The Collyweston Slate is a massive, fine-grained sandy limestone when fresh (Figures 11 & 12); after being left out in the frost over the winter it can be split into slate-like pieces. Collyweston slates have been recorded as far back as Roman times and have been since used to roof many important buildings. Like the Welsh slates each size and type of slate was given a name of which there were 28 in total. The names included Outrills, Mopes, Mumford, Job, In bow, Out bow and many more. The fauna of the Collyweston Slate includes many lamellibranchs but also has a rare fossil known as the 'water spider'; it is a gastropod called *Phyllochilus bentleyi*.

A surprise visit to the Weldon Stone Company quarry enabled me

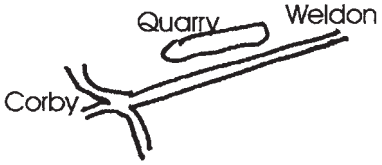

Figure 13. Sketch map to show the location of Weldon Stone Quarry.

to see the Weldon Stone *in situ* (Figure 2 & 13). The main Weldon quarry began working around 1890 but Weldon stone had been worked on quite a large scale by the 13th century. It was used in the building of King's College, Cambridge and Rockingham Castle. It had been extracted by hand sawing horizontally and splitting off by hammering wedges into vertical holes drilled in the stone (Hill 1999).

Lincolnshire Limestone (Table 1) is divided into Upper and Lower formations. It is not found in the Kettering area but extends from the north of Kettering into Rutland and Lincolnshire, its thickness rarely exceeding 40 feet (Figures 14 & 15). The basal beds rest conformably on the Lower Estuarine Series/Grantham Formation. The most characteristic basal bed is the Collyweston Slate, a fissile limestone which is used for roofing slates.

In the Lower Lincolnshire Limestone there are at least 4 distinctive rock types:

Sandy fissile limestones such as the Collyweston Slate

Fine-grained oolith-pellet limestones

Oolith-pellet limestones with large and small ooliths

Medium to coarse-grained oolites

Figure 14. Upper Lincolnshire Limestone at Weldon Stone Quarry.

Figure 15. Upper Lincolnshire Limestone at Weldon Stone Quarry.

They generally contain an abundant fauna dominated by molluscs.

The Upper Lincolnshire Limestone is characterised by an abundance of shelly debris and by a coarse texture. Where the Upper limestone overlies the Lower limestone, the surface of the conformity is extensively bored. The Upper limestone contains many brachiopods.

The base of the Lower Lincolnshire Limestone was deposited in shallow marine waters of coastal swamps or delta flats.

The Lincolnshire Limestone stratigraphy is as follows:

Lincolnshire Limestone:
- Barnack Rag and Weldon Stone
- Ketton Stone
- *Acanthothyris crossi* bed
- Cementstones
- Nerinea beds
- Collyweston Slate

Grantham Formation

Northampton Ironstone

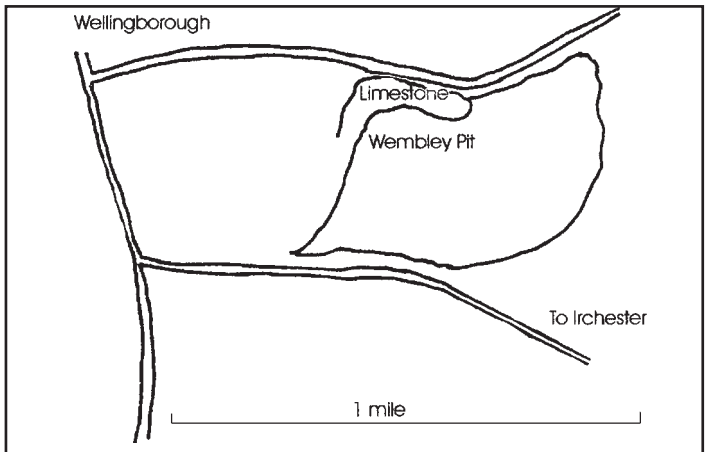

Figure 16. Sketch map showing the location of Wembly Pit, Irchester.

To end to the search, I decided to visit Irchester Country Park (Figure 2 & 16) where I knew there was a very good outcrop in an old quarry. Twenty years ago, this was very accessible and there was also a geological trail complete with trail leaflet. I was disappointed that the trail was no longer accessible as the way down into the quarry was very difficult and the quarry face was obscured in the lower parts by the undergrowth and many small trees. However the views from the main path overlooking the quarry were still quite good and, using the old leaflet, I was able to observe and name the beds I could see (Figure 17).

The quarry was the old Wembley Pit, named in 1924 when production began, the year of the Empire Exhibition at Wembley. The overburden (consisting of the Blisworth Limestone, the Rutland Formation and the Grantham Formation) was removed and then the underlying ironstone was blasted and taken away to be calcined. After 1941 the worked out parts were left in the hill-and-dale formation and planted with larch and pine trees. In 1971 the quarry and some of the surrounding area was purchased by Northamptonshire County Council as a country park.

Large boulders of the limestone, containing many fossils, have been brought to the main path so they can be inspected by all who

Figure 17. The Lincolnshire Limestone exposure at Irchester Country Park.

find the local geology of interest. Currently, the local RIGS group is negotiating with the council to gain better access to the quarry.

However, the history of iron-making in this area goes back much further to 200BC. During the quarry operations at another site in Twywell an Iron Age settlement was uncovered, one of several in this area. The Romans also smelted iron in 'ferraria' in Corby while, during the Plantagenet times, there were furnaces at Geddington. During the reign of Queen Elizabeth I a ban was enforced on the cutting down of trees for charcoal burning and hence iron smelting, as Queen Elizabeth wanted the trees cut down to build her Armada.

There is much recording to do here in order to preserve what is left for future generations. The local RIGS group is working hard to gain protection for some of these sites. This is a short preview of a larger project which will take many months to complete.

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Author

Gladys has been a member of the OUGS since 1974 and is currently undertaking private research locally and in the western states of the USA.

Across the Ethiopian Highlands

Kate Fereday

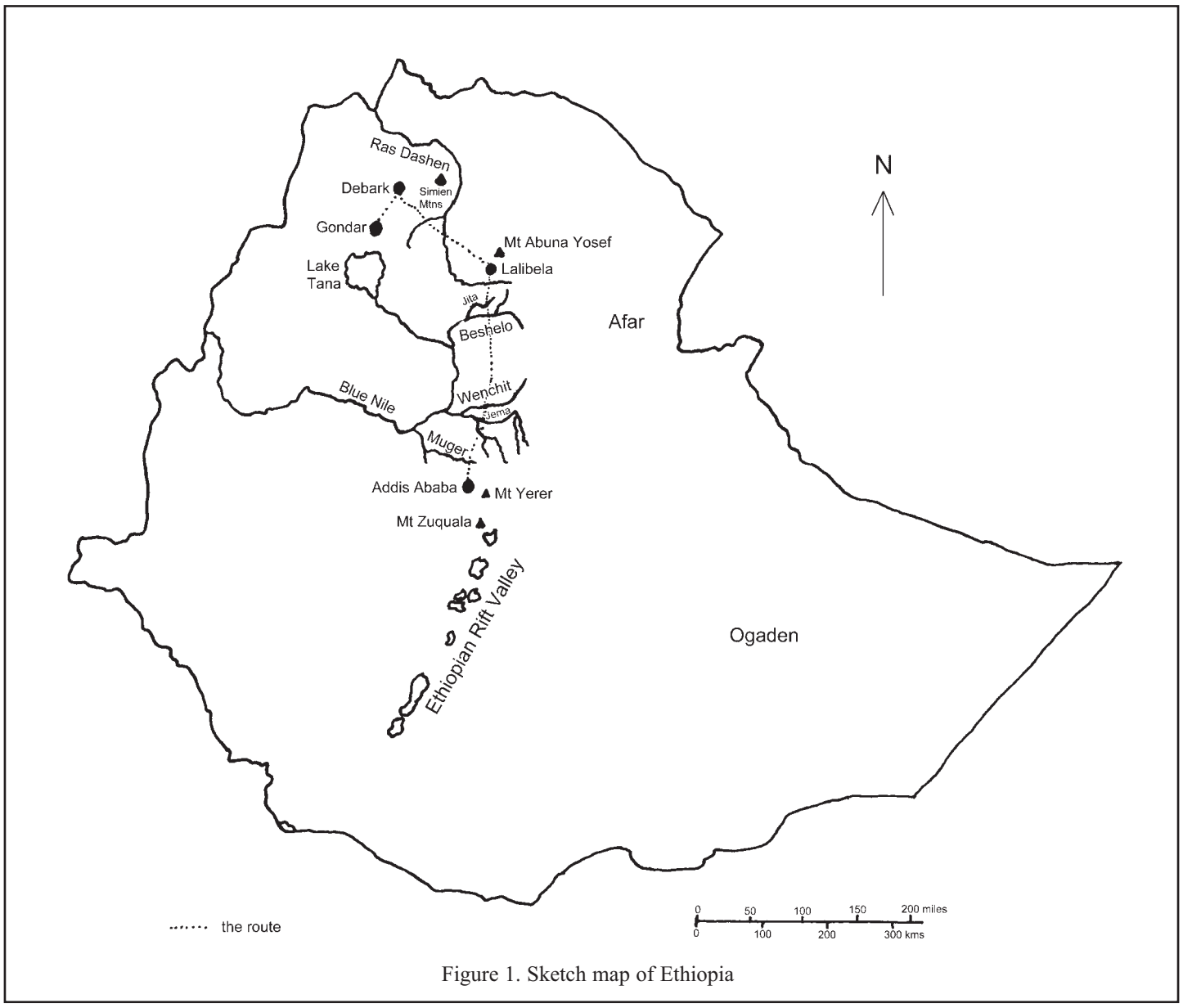

Figure 1. Sketch map of Ethiopia

On 28 November 1999 an unlikely group of travellers set out from Addis Ababa to trek north across the Ethiopian Central Highlands (also known as the Western Plateau) via Lalibela to the Simien Mountains, then south-west to the city of Gondar. The trek across more than 640km of challenging terrain was to take six and a half weeks.

Our group comprised an Englishwoman (me), an Ethiopian (Adem Ibrahim), a miniature poodle (Judy) and a donkey (Dinkenesh, a name that can have several meanings, my favourite being 'she who is famous for being first').

Having completed S339 *Understanding the Continents: Tectonic and Thermal Processes of the Lithosphere* in 1998 and having organised the OUGS field trip to Ethiopia in 1999, my interest in mantle plumes and continental flood basalt provinces had been stimulated. The Ethiopian province, which is relatively young and still active, is thought to be the surface expression of the Afar

Figure 2. Ready to be off, Kingfisher House, Addis Ababa

mantle plume. The Afar region of north-east Ethiopia is a triple junction where the Ethiopian Rift meets the Red Sea and Gulf of Aden spreading ridges, all of which have a close association with the province.

However, the main reason for doing the walk was not my amateur interest in geology, but rather to have an adventurous holiday. It was also a sponsored event and raised over £2,000 for The Kindu Trust, a charity that helps orphans and abandoned children in Ethiopia.

At an altitude of 2300m, Addis Ababa is the third highest capital city in the world. We began our journey at Kingfisher House, The Kindu Trust's family home for ten orphans, which is located in the south-west of the city. We skirted round the suburbs and climbed up into the Entoto Hills to the north, stopping to take a last look south into the Ethiopian Rift Valley. From that viewpoint, two large extinct volcanoes on the western flanks of the wide valley dominate the southern horizon: Mount Yerer (3100m, 4Ma, with a deep, semi-collapsed caldera) and Mount Zuquala (3200m, only 7Ka, with a crater lake and wooded slopes).

The Ethiopian Rift is the northern segment of the East African Rift system which separates the Nubian or African (west) and Somalian (east) continental plates. The rift in Ethiopia began about 15Ma and magmatism and seismic activity still occur there today. A graben about 800km long and up to 100km wide, the rift has a mean elevation of 1600m and is marked in southern Ethiopia by a chain of lakes. Its margins have an average height of 2200m and comprise Tertiary volcanic rocks, whereas the rift floor is covered by Quaternary basaltic, trachytic and rhyolitic lavas, pyroclastic flows and fall deposits. Research on extension fractures, elongated volcanic vents and linear clusters has revealed that the extension direction of the Ethiopian Rift is oriented NW-SE to NNW-SSE (Korme *et al*, 1997).

On our first night we camped in a farm compound, safe from attack by the packs of hyenas that roam the hills. In the morning the donkeys, including Dinkenesh, were let out from their stable and I noticed a large wound on the hindquarters of one of the animals. My grasp of the official first language of Ethiopia, Amharic, is basic, so Adem interpreted for me when our host explained that a hyena had recently attacked the donkey nearby in broad daylight.

For the rest of the journey, we always looked for a farm where we could spend the night. If we were too tired to put the tent up, we would sleep on goatskins in our host's *sarbet* (grass house) along with his family. These thatched mud huts were usually flea-infested, so I much preferred sleeping in our homely tent. Once, in the remote and sparsely-populated Tekeze area, we could not find a farm when darkness fell, so we tied Dinkenesh to a tree and slept on the ground close to her; fortunately, the night passed without incident.

Leaving the Entoto Hills behind us, for the next two days we walked through glorious golden fields. The four-month rainy season had ended in October and now it was harvest time in the Highlands. Everywhere the peasant farmers were using sickles to reap their ripe crops of wheat, barley, oats and *tef*, as well as grass for hay. The valleys between the low rolling hills were dotted with long stacks of corn and hay, resembling great loaves of freshly-baked bread.

Figure 3. Breakfast stop next to a tributary of the Muger River, south of Chancho

Suddenly on the fourth day we came upon a deep gorge where the plateau had been cut by the Muger River. This was our first opportunity to see a 1000m cross-section of the flood basalt pile, which at that point comprises about 800m of Alaji/Aiba Tertiary basaltic lava overlying 200m of sandstone.

Across Ethiopia flood basalts cover an area of 600000km^2 (George 1999). Early tholeiitic flood basalts were erupted before 30Ma. However, the most voluminous period of basaltic magmatism was 30-20Ma, during which an amazing 3 x 10^{8}km^3 of the Trap Series flood basalts erupted in Ethiopia and Yemen, alkaline basalts grading upwards into transitional basalts (S339, Block 2, p42).

The average thickness of the Trap Series lavas is 2000m, giving an eruption rate of 0.0002myr^{-1}. Assuming instantaneous eruptions of lava flows 10m thick, one major eruption must have occurred approximately every 10000 years. After 23Ma, the Ethiopian Traps included more silica-rich layers, with trachyte flows and rhyolitic pyroclastic rocks (S339, Block 2, pp42-43)

The Trap Series lavas were erupted from volcanoes and fissures, each with its distinctive basic magma composition from which the more evolved products were derived (S339, Block 2, p43).

Figure 4. Ethiopian Highlands

Continuing our journey, we turned east and rejoined the main road north from Addis Ababa to Debre Markos. We spent the

night at a cheap hotel (60p a room) in Muke Ture and woke to an icy frost early the next morning.

Walking in single file (Judy at my heels, followed by Dinkenesh carrying our tent, two blankets, clothes, food and water, then Adem bringing up the rear), we stayed next to the road for half a day, battling against a cold northerly wind. Our presence provided some entertainment for incredulous passengers on passing buses, enduring a long, uncomfortable two-day journey to or from Gondar. At Debre Tsige we left the road to walk cross-country to Debre Libanos. By now the sun was high and the cold wind had ceased to blow. As we walked across the fertile agricultural land, I marvelled at the multitude of colourful butterflies while Dinkenesh was more interested in the crops of green beans on either side of the footpath. Early that afternoon we came to an enchanting place called Jibgure where a distinctive lava flow at the top of the basalt pile was clearly exposed. We enjoyed a picnic in the valley below the outcrop while Judy snoozed in the shade and Dinkenesh grazed contentedly. This was one of many memorable picnics we had in breathtakingly beautiful surroundings.

Figure 5. Jibgure, near Debre Libanos

Upon reaching Debre Libanos, we decided to stay there for two nights so that we could have a rest day. The town is situated near the top of a deep gorge, at the bottom of which flows a river - a tributary of the Jema River which, like the Muger River, flows into the Blue Nile far to the west. The town of Debre Libanos grew up on the southern side of the gorge where the vegetation is lush as a result of the shade created by the great columnar basalt cliffs towering above. Taking Dinkenesh through the woodland so that she could drink at a fast-flowing highland river to the east of the town, we saw massive house-sized chunks of columnar basalt strewn where they had come to rest after tumbling down from the top of the gorge.

Heavily disguised in traditional white, hand-spun, woven cotton Ethiopian attire, I walked to Tekle Haimanot Church shortly after sunrise the following morning. The Church was already full, so I sat near the main gate listening to the Ethiopian Orthodox priests chanting inside and to the eerie low hum of the crowd in front of the building. The Church is named after a famous Ethiopian archbishop who founded the great monastery at Debre Libanos in the 13th century.

The following day we wound our way down into the gorge. At first the path was dangerously steep, so Dinkenesh's agility was tested. She coped very well. Half way down we stopped for

Figure 6. Zegalamelmariam

breakfast and sat overlooking a *sarbet* village called Zegalamelmariam below us. It was perched on red sandstone below high basalt cliffs and a spectacular waterfall.

Lower down we ate delicious sorghum, picked from the field for us by a friendly farmer. Further down still we feasted on freshly cut sugar cane.

Figure 7. Debre Libanos Valley

After crossing the river, we began the long climb up the northern side of the gorge. We were joined by two men who were returning from Debre Libanos to their farms at Yedano. On the way they showed us a great cave within a columnar basalt layer. Water dripped from the ceiling and formed a pool outside. Our walking companions told us that the vertical shaft in the top of the cave was reputed to have been made by *Abuna* (Archbishop) Tekle Haimanot when he was on his way to Debre Libanos. The afternoon light was fading, so there was no time for me to examine the cave and determine whether or not there was a geological explanation for the shaft.

That night we stayed in the compound of one of our new friends who was called 'Biscut'. His parents gave him this name because he was, in their opinion, biscuit-coloured! Most Ethiopian names have meanings and many reflect the character or appearance of the child they are given to.

Figure 8. View to the north-west, near Lemi

The following day we continued the climb to the top of the plateau. An Ethiopian gentleman we met did not like to think of me struggling up such a steep path, so he organised equine transport for me. Judy lay across the front of the saddle and slept while the sturdy mule carried us both up to the small town of Lemi, with Dinkenesh and Adem following behind.

During the past week, I had used up almost all Judy's dog food and had not seen any meat that I could buy to feed her. Ethiopian peasant farmers cannot afford to slaughter their animals except for celebrations or religious holidays so they rarely eat meat, which suited Adem and me as we are vegetarians. However, I decided that it would be best to return the carnivorous Judy Poodle to Kingfisher House where the local butcher could satisfy her dietary preferences. From Lemi it is possible to go to Addis Ababa by bus in about three hours at a cost of 10 birr (80p). So Judy and I travelled to Addis Ababa while Adem and Dinkenesh enjoyed a rest. I returned to Lemi the next day, laden with pizza and other edible treats prepared by the house-mothers at Kingfisher House.

With Judy Poodle in safe hands, Adem, Dinkenesh and I continued north, crossing the Jema River on the way to Alem Ketema. It was extremely hot in the bottom of the river valley. Adem and I swam in the cool, fast-flowing water and took the opportunity to fill our water bottles (using iodine drops to sterilise the water) and to wash our clothes.

Now, when I reflect on the journey, the memory of Ethiopia's beautiful rivers is what sticks in my mind. These rivers have, over millions of years, carved out spectacular gorges in the massive lava pile. People outside Ethiopia often perceive it as a land of desert and famine. This may aptly describe the drought-ridden Ogaden and Afar areas in eastern Ethiopia, but during and after the rainy season (June to September), the rivers of the Central Highlands are full of water and the valleys are lush with vegetation, including banana and sugar cane plantations in some places.

The great Blue Nile Gorge is 1500m deep. Although our route did not take us to the Blue Nile, we waded across four of its important tributaries in the regions of North Shoa and South Wollo, each memorable in one way or another: the Jema River (deep and cold), the Wenchit River (wide and sluggish), the Beshelo River (shallow and warm, with many fish) and the Jita River (with colourful pebbles). Our encounter with each river involved a long, winding descent into the bottom of the valley, followed by many hours toiling up the other side. In this way we went down and up many stratigraphic sequences.

Figure 9. Multi-tiered curvi-columnar entablature of lava near the top of the Jema Valley

Figure 10. A donkey's eye view of the Jema Valley

A day after climbing out of the Jema Valley, we reached Alem Ketema and found a cheap hotel as the sun set. What is striking about this remote town is that it is built on hard white, siliceous rock, giving an ideal walking surface (there were no vehicles).

We continued north through the Merhabete area and crossed the wide valley carved out by the Wenchit River. We climbed up from the river as the sun was setting and in the valley wall there was a spectacular curvi-columnar entablature of multi-tiered basalt lava, tens of metres high.

A tier is a set of regular, vertical joints occurring between two horizontal levels in a lava flow. Multi-tiered lava flows are associated with high volumes of magma, such as flood basalts.

Figure 11. Wenchit River

When a lava flow cools, colonnade joints of regular, vertical columns typically form at the top and bottom of the flow and the interior forms a pseudo-columnar (wide-spread, irregular columns) above a curvi-columnar (narrow, radiating columns) entablature.

The internal joints in the basalt rock are caused primarily by contraction of solidified lava. If water floods the lava surface it will seep down through the joints, modifying the isotherms below, so that fan-like columns (a curvi-columnar entablature) are produced. Meanwhile, the upward-moving cooling front forms more regular columns (the colonade) below (Lyle 2000).

Marvelling at the radiating columns of basalt in the massive lava flow, I wondered if I was the first person with an interest in geology to set eyes on this amazing sight and appreciate its history. Monkeys sat above the cliffs. A crescent moon gave sufficient light for us to reach the safety of a nearby farm after dark.

The next morning we scrambled up on to the top of an extensive plateau, happy in the knowledge that we could enjoy walking across gently undulating countryside for the next week, until we reached the deep valley created by the Beshelo River. At an altitude of 3000m, it was cold and windy, so in this area farmhouses and outbuildings are built of basalt rocks. We passed a Church which had a wall around the compound built of vertical columns of basalt, some a metre long. In the surrounding fields, erosion had exposed the surface of a lava flow, the hexagonal tops of the upper colonnade creating a basalt pavement.

We walked for days through arable farmland, following a dirt road and sometimes taking shortcuts cross-country. Our route took us via Degolo, Were Ilu, Kabi (nestling below Mount Yewel, an extinct volcano), Tulu-Owlia (where we were detained half a day by police who suspected that we were spies), Fitto (our first encounter with the endemic Gelada baboons), Ajibar (excellent bread and delicious honey!) and Tenta.

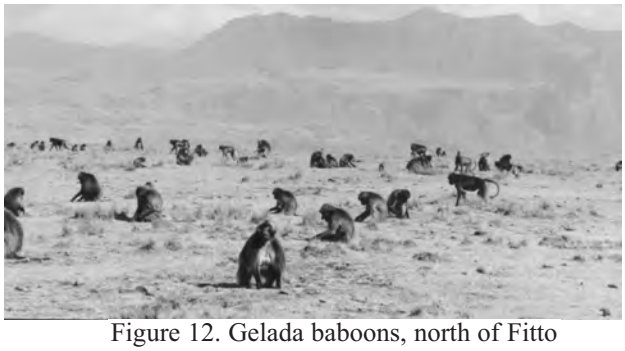

Figure 12. Gelada baboons, north of Fitto

Figure 13. Magdala

Looking west from Tenta, we could see Magdala, the mountain stronghold of the Emperor Theodore of Abyssinia, which was captured by the British in 1868 during a successful military campaign to rescue hostages, including a British consul and an envoy sent by Queen Victoria. Theodore was prone to mad, irrational rages. Once he ordered almost 200 of his Ethiopian prisoners (political enemies and their families) to be thrown off the high cliffs of Islamgi, the plateau just below his main fortress at Magdala.

Theodore released all 59 hostages (mostly Ethiopians and half-castes, with just a few Europeans) before he committed suicide. As we walked north with my beloved Dinkey Donkey, I recalled the terrible loss of more than 28600 animals (mainly pack animals, including elephants) that had died, been destroyed or abandoned in the course of that costly British expedition. Passing through Tenta, I did my bit to make amends by rescuing a hen that had been left hanging upside-down outside a hut.

North of Tenta, the plateau ends and the road zigzags down into the Beshelo Valley. The new road cuttings reveal a fascinating stratigraphy.

Figure 14. Beshelo Valley

We reached Wegel Tena two days later, arriving in the evening having walked for over an hour by the light of the full moon. I could not help feeling a certain thrill at being there, because of the famous Wegel Tena basalts.

Wegel Tena basalts contain relatively large amounts of MgO, indicating that they have undergone less fractional crystallisation than other basalts and are more primitive. In addition, they have a remarkable helium isotope ratio, with over 15 times more ^{3}He than ^{4}He (a much bigger ratio than in ordinary basalts). It is

believed that the ^{3}He reservoir is found in the Earth's core and so basalts containing this high isotope ratio are extremely rare (so far they are only known to occur in Hawaii, Iceland and Ethiopia). Usually uprising magma has degassed enough to lose much of its ^{3}He. For the Wegel Tena basalts to show such a high ^{3}He/^{4}He ratio, they must have had direct contributions from a mantle plume that had escaped interactions with the lithosphere and crust (George 1999).

From Wegel Tena we walked west to look for a way across the deep valley in which the Jita River flows. We inadvertently found ourselves climbing up the far side of the gorge as darkness fell, and this time we could not benefit from the light of the rising-moon because we were in the shadows right at the bottom of the valley. We stumbled about by faint torchlight, avoiding the precipitous drop down to the rocks below and worrying about hyenas, and were most relieved when we discovered a *sarbet* near the footpath where we were able to seek refuge for the rest of the night.

Figure 15. Dawn in the Jita Valley

The next day it took us three and a half hours to climb out of the Jita Valley. At an altitude of about 2700m, I spotted plant fossils in a large mudstone rock. The fossilized stems and leaves of ancient plants were clearly visible. I had visited the fossil collection in the Department of Geology and Geophysics at the University of Addis Ababa, but these were the first fossils I had ever observed in the field in Ethiopia.

After continuing across the plateau, the following morning (Christmas Day) we reached the top of a great escarpment, with a tremendous view north towards Mount Asheten towering above the small town of Lalibela. The escarpment, which we could see extending far to the west, marks an E-W fault. It took us 12 hours to descend to the Tekeze River, cross the arid hills between it and the Kechinabeba River, then climb up to Lalibela, which is situated on a wide ledge of tuff.

It seemed rather appropriate that a man, a woman and a donkey should trudge wearily out of the darkness and through the gateway of the Lal Hotel to ask if there was any room at the inn. Fortunately there was.

Figure 16. View north to Lalibela early on Christmas morning

We spent three nights in Lalibela, cleaning ourselves and our clothes, resting, eating well and writing up our journals. There were destitute children asleep on the streets at night. I hoped that one day The Kindu Trust would set up a family home there to provide shelter for desperate boys and girls in this drought-ridden area of Lasta.

Lalibela is famous for its mediaeval rock-hewn churches. These were carved out of the pink rhyolitic tuff – the Alaji ignimbrites which erupted around 28.8Ma. The tuffs are highly siliceous (over 70 wt % SiO_2, compared to 45-52 wt % SiO_2 in the flood basalts) and were deposited on top of basalt, at the end of an eruptive sequence. One theory is that extensional tectonics stopped and the magma ponded in the crust, undergoing crystal fractionation, assimilating the surrounding rock and producing volatile gases. As the magma became light enough to start rising again, the gases expanded, causing explosive eruptions of ignimbrite covering an extensive area (George 1999).

Figure 17. *Bet Giorgis* (St George's Church), Lalibela, below Mount Asheten

From Lalibela we proceeded north-west and began our 12-day walk across the great Tekeze river system to reach the western side of the Simien Mountains.

Our journey took us down to the Tekeze River at an altitude of about 1000m. To the north, the Simien Mountains rise up to over 4000m - Ras Dashen at 4620m is Ethiopia's highest mountain (it

is the fourth highest in Africa). The Tekeze flows north, along the eastern side of the Simien Mountains, then turns west, flowing into Sudan where it joins the Nile.

The low-lying Tekeze area is hot, dry and empty. There were not even any hyenas there. The people inhabiting this remote area are the poorest we came across. In places there are no clinics or schools; the people barely scratch a living from the arid land. Malaria kills many. It is an area rich in minerals, which here are exposed deep in the flood basalt pile.

The Tekeze was the deepest river we encountered. The current was strong and I lost my footing as we waded across. To prevent being swept away to the hungry crocodiles waiting downstream, I flung my arms around Dinkenesh's neck and was saved.

Figure 18. Nilli River, a western tributary of the Tekeze

It was a relief to climb up into the Simien Mountains where the grass was lush and green, the horses and people well-fed, and the air fresh and cool. We spent two nights in the small town of Debark at 2900m and visited The Kindu Trust's Riggs House, home to ten children in need.

Figure 19. Simien Mountains (view to the east)

At Debark the Tertiary basalt pile is very thick. Just to the north of the town, a great escarpment marks an E-W fault related to Red Sea extension. Almost 2000m of basalts and tuffs are exposed at the edge of the plateau. Age-dating has shown that this remarkably thick sequence may have erupted in less than 2My, which supports the theory of decompression melting above a mantle plume because this is thought to be the most rapid way to generate a lot of magma (George 1999).

From Debark we travelled across the south-western flanks of the Simien Mountains for two days. It was mostly pleasant walking across undulating grassland. At last, at 12 noon on 12 January 2000, we came round a hillside and could see Gondar far below. It stands on a basalt ridge about 40km north of Lake Tana, the source of the Blue Nile. Lake Tana was just visible in the distant haze. Gondar's shiny tin roofs glinted in the sunshine. By now we had no money or food left, but we were in good spirits and eager to reach our final destination. We very much looked forward to eating a square meal and sleeping between clean cotton sheets.

Figure 20. Gondar

Taking the most direct route, we estimated that it would take us two hours to reach the city. In fact, it took us six hours because half way along the footpath we were intercepted by armed militia who were suspicious because we were approaching Gondar on foot from the north (the direction of the Eritrean border). Since the outbreak of the Ethio-Eritrean War in May 1998, districts within Ethiopia had been guarded by militia. We encountered many of them north of Lalibela and were sometimes detained for hours.

After a harrowing afternoon, we eventually arrived in Gondar after dark. We were dirty, weary, hungry and thirsty – but I was delighted to be slimmer and fitter than I had been for 20 years! The families at the The Kindu Trust's projects in Gondar (Spear House and Jephcott House) gave us an enthusiastic welcome.

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Kate Fereday is an undergraduate who has just completed her sixth year of part-time study with The Open University. In 1998 she founded The Kindu Trust. In 2000 she set up The Dinkenesh Fund, a charity funding small projects to assist animals in need in Ethiopia. For more information about either charity, please contact Kate by telephone on 01752-550450 or by e-mail on `kate.fereday@altavista.net` or by writing to her at PO Box 9, Plymouth PL1 3YJ. Kate splits her time between Ethiopia and the UK and is currently writing a book entitled 'Dinkenesh' about her journey across the Ethiopian Highlands.

OUGS Presidential Field Trip to Germany, led by Dee Edwards, August 1998

Will Jones, John Downes, Marilyn Mayes, Angie Marchant & Irvine Walker

The Ries and Steinheim Craters

The Ries Crater is an approximately circular area of relatively low lying and generally flat ground set in a hilly part of Bavaria. The origin of the structure was the subject of much speculation for over a century; the commonest explanation for large circular depressions is that they are calderas and indeed the Ries was usually interpreted as volcanic during the nineteenth century. However, calderas are found on top of large volcanoes whereas the Ries structure contains few apparently volcanic rocks. There are outcrops of a kind of breccia containing glass inclusions that could be claimed as a tuff, but there are no lavas. For a while it was claimed that the Ries was representative of a class of features, of which a few others were known, called cryptovolcanic or cryptoexplosion structures. These resulted from huge eruptions of volcanic gases without much accompanying liquid or solid rock. There was even an attempt to explain the Ries as the result of glacial erosion. An impact origin for the crater, first suggested in l904, became the generally accepted explanation in 1960 when Ed Chao found microscopic coesite crystals in the suevite. This mineral is a high pressure form of SiO_2 originally synthesised in the laboratory and subsequently found at Meteor Crater, Arizona. The Ries was only the second geological occurrence of coesite known.

The Ries crater is one of the most important localities, perhaps second only to Meteor Crater in Arizona where field work led eventually to the recognition of meteorite impact as an important geological mechanism. Now there are about 150 impact structures known around the world. The Ries remains important because it is one of the best explored: it is the type locality for the impact-produced rock type *suevite* and one of only two craters definitely related to a tektite strewn field.

The Steinheim Crater lies close to the Ries and has been the subject of much study and speculation. It is the type locality for shatter cones. Together the two craters form a valuable pair as they show the results of impact of two bodies, which were the same in all but size, into virtually the same target rocks at the same time. Figures 1 & 2 are a map and geological cross section showing both craters.

Formation of the crater

In the Ries, a basement of pre-Variscan gneisses and Variscan granites is overlain by 250m of Triassic sandstones, 170m of lower and middle Jurassic shales and finally 350m of Upper Jurassic limestones. The succession dips gently to the south-southeast where it is overlain by Tertiary sediments along the Danube valley.

The limestones are relatively resistant to erosion and their outcrop is marked by a range of hills running east-northeast known as the Alb. This high ground is in the form of a cuesta with a steep scarp slope to the north and a gentle dip slope to the south. The older Jurassic and Triassic rocks outcrop on the lower ground to the north.

15Ma ago, when the meteorite struck, the limestone was horizontal and had a thin cover of Tertiary sands. The explosion punched

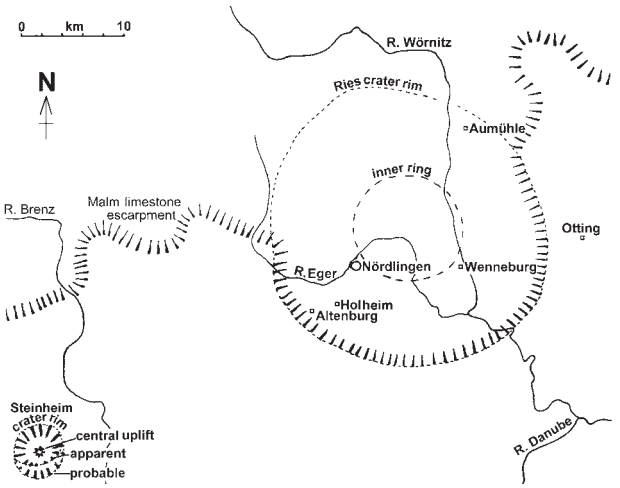

Figure 1. Outline map of the Ries and Steinheim craters. Small squares are localities visited during the trip.

a hole in the limestone surface. Subsequently the rocks were tilted down to the south-southeast and eroded away on the north-northwest side. The result is that today the Alb is in two parts, the Schwäbische Alb in the southwest and the Frankische Alb in the northeast, separated by the low ground of the Ries. The crater appears now as an embayment in the limestone escarpment in the shape of two thirds of a circle of about 29km diameter. The north and north-west edges of the crater lie beyond the escarpment and are much less pronounced topographically. The crater floor is fairly flat and the surrounding hills rise to about 200m above it.

The object that produced the crater is believed to have been a stony meteorite about 1km across, much the same diameter as the walled town of Nördlingen and would have arrived with a velocity of something like 20kms^{-1}. The impact released energy equivalent to 18 000 megatons of TNT.

The meteorite hit the ground at a speed which was several times faster than seismic waves travel through rock, so the energy of the impact was unable to disperse away from the point of contact. A shock wave therefore passed into the earth just in front of the meteorite while another moved back through it. Between the two shock fronts, earth and meteoritic material were subjected to pressures of several hundred GPa, as much as the pressure at the centre of the Earth, and to temperatures up to 30 000°C, 9 times hotter than the surface of the sun. The meteorite carried on down into the earth until, in less than a tenth of a second, it had penetrated to a depth about equal to its own diameter of 1km. At this point it had melted and vaporised to the extent that it was no longer recognisable as a separate body. A crater grew when much of the meteorite's kinetic energy was used up in expelling rock from the impact site. Above the crater, vaporised rock formed a fireball which began to float upwards as a mass of extremely hot gas with a lower density than the surrounding air.

The effect on rocks of extremely high pressures and temperatures applied over very short times is called shock metamorphism. The degree of shock metamorphism which a rock has experienced can

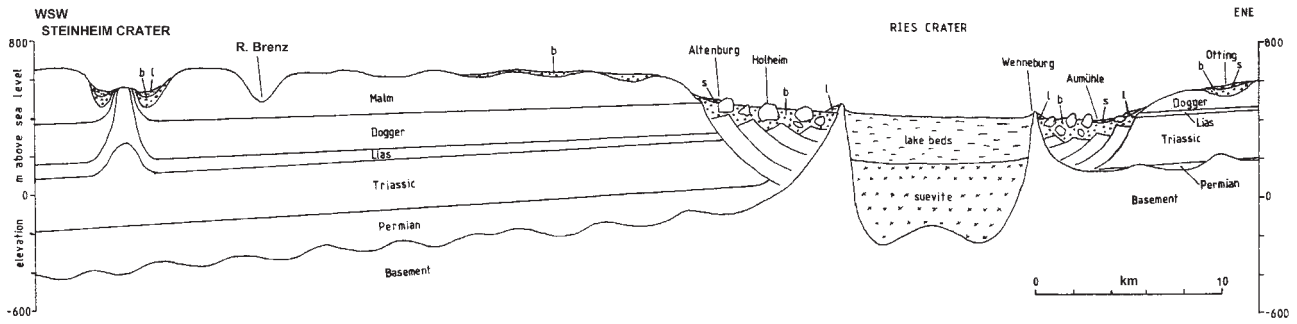

Figure 2. Sketch of geological cross section through the Ries and Steinheim craters. Vertical exaggeration is x10. The localities visited are marked to show their geological relationships, the positions being only approximate.

be deduced from a series of changes visible in hand specimen or thin section. The whole range of shock metamorphic changes are present in specimens from the Ries. As the shock front expanded, the degree of shock metamorphism suffered by the ejected material decreased. Rock from the immediate vicinity of the impact point was vaporised whereas a surrounding shell was melted. At greater distances the material was subjected to the characteristic series of effects from vitrification of quartz and felspar grains at high degrees of shock down to planar deformation features in quartz and kink banding in micas. However, the majority of the material ejected from the crater came from regions where the pressures and temperatures were too low to produce shock metamorphic effects.

Each individual piece of debris thrown out of the crater travelled along its own ballistic path, but the ejected material as a whole had the shape of a funnel or inverted cone which swept outwards away from the crater. When the rock fragments landed they still had a considerable horizontal momentum and so continued to move outwards, rolling and gliding, as a kind of debris flow, incorporating local material as they went.

The crater reached a final depth of 1-4km and a diameter of 12km after about 10 seconds. As soon as this transient crater had grown to its maximum size, it began to be modified. The floor rose up to compensate for the removal of rock above it. At the same time the sedimentary rocks forming the upper part of the crater wall started collapsing, with large blocks sliding downwards and inwards.

Meanwhile, the fireball was rising and expanding. Part of it separated as a relatively dense mixture of hot gas, liquid drops and rock fragments which fell back to the ground, depositing the tuff-like rock called suevite (Figure 3). The formation of the Ries Crater and the deposition of its ejecta blanket was now finished, only about five minutes after it began.

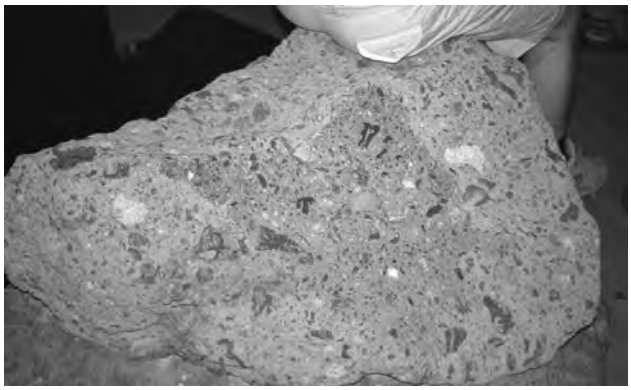

Figure 3. Suevite: glassy shards in an ashy matrix.

The fireball continued to rise and may have failed to find an equilibrium level in the atmosphere because of its great size and so finally broke out into space. Drops of liquid rock carried up in the fireball eventually fell back to earth up to 400km to the east as the Moldavite tektites. The material of these cm-sized translucent green glass objects is believed to have come from a thin layer of Tertiary sands at the ground surface that vaporised at the very beginning of the impact.

The crater after the impact

The present crater rim marks the outer limit of slumping of the sedimentary rock cover during the crater modification stage. Within the modern crater a partial inner ring of hills of basement rocks 9km in diameter marks the uplifted top of the basement around the transient crater. The basement is up to 600m above its original position. A borehole drilled within this crystalline ring in 1973 found the basement surface at a depth of 600m; it had presumably been upraised by an even greater amount than the inner ring.

The borehole penetrated 600m of highly fractured basement rocks. This fracturing of the basement probably continues to a great depth as gravity and seismic measurements indicate that anomalously low density and low velocity basement rocks extend to a a depth of 7km below the crater centre. An important discovery in the drill core was the presence of metallic veinlets in the basement just below the crater floor. The metal is believed to have come from the meteorite itself and its high Cr content indicates that this was a stone rather than an iron meteorite.

The borehole found 390m of suevite overlying the basement. The suevite differs from that exposed at the surface in not having large glass inclusions. The two types are therefore distinguished as fall back and fall out suevite respectively. Above the suevite, the borehole passed through 250m of lake bed sediments.

Between the inner ring and the limestone escarpment, i.e. between the transient and final crater rims, is a zone of large tilted "megablocks" up to 1km across and consisting of rocks from the sedimentary cover. The megablocks are set in Bunte Breccia overlain by patches of suevite. Bunte Breccia overlaps the crater rim and forms a mantle generally up to 90m thick but increasing to 200m in buried valleys. This extends to 17km from the crater centre to the south and east but has been been eroded away in other directions. Isolated Jurassic limestone blocks up to a few

metres in diameter, believed to have been ejected from the crater, are found as far as 70 km from the centre towards the south east.

The Bunte Breccia consists of material of all grain sizes from rock flour up to large boulders. The megablocks can be regarded as the extremely large end of the size range. The clasts come from all the formations of the Mesozoic sedimentary cover with a small minority from the basement. There is a tendency for rocks from the lower part of the sedimentary succession to become more abundant in the upper part of the Bunte Breccia. Shock metamorphism is not apparent in most of the clasts and where present it is only of low grade. However, some of the fragments show signs of plastic deformation including strong folding, which requires burial to a depth of several kilometres under normal circumstances. They must have been subjected to moderately high pressures at some time, probably during the debris flow stage.

After the impact, crater ejecta blocked the nearby river valleys so that the crater became an internal drainage basin disconnected from the regional drainage pattern. A lake developed in the depression which fluctuated in level and was usually saline. Over the next 2Ma the crater gradually filled up with lake sediments. These were mostly clays and marls but limestones developed in the shallow areas around the edge of the lake and on the submerged crests of the basement hills.

Uplift of the area in the Tertiary led to reconnection to the regional system of rivers draining south to the Danube. This largely removed the soft clays and marls although the patchy limestones were more resistant. The 1973 borehole showed that 250m of lake sediments are still present below the surface in the inner crater. The crater has thus been only partly exhumed. The present level of erosion corresponds approximately to the top of the ejecta in the outer crater, whereas the inner crater remains buried under later sediments and is not an obvious topographic feature.

Steinheim crater

The Steinheim crater is 3.4km in diameter with the floor 90m below the rim. In the centre is a hill 900m across and 50m high. This makes it a fine example of a complex crater that is, one with a central uplift (Figure 4).

Figure 4. Picture of Steinheim crater on the wall of the museum.

The morphology of the crater is disrupted by a younger valley which cuts east-west along the southern wall of the crater. The low ridge between this valley and the floor of the crater, known as the Burgstall, probably represents only the lower part of the crater wall. The true rim most likely lies along the hills south of the valley (Figure 1). In that case the diameter of the crater would be more like 9km.

The rocks forming the surface of the surrounding countryside are gently dipping limestones of the Upper Malm, but Lower Malm limestone occurs dipping outwards around the flanks of the central uplift. The crest of the hill consists of megablocks of Dogger and Lias sandstone and shale with near vertical dips. The outcrops of limestone around the central uplift contain shatter cones, cone shaped fractures with striations radiating from the apex. These features were originally described at Steinheim but have subsequently been found at many impact structures and are regarded as diagnostic of an impact origin.

Drilling on the low ground of the crater floor has revealed lake beds overlying a layer of breccia up to 70m thick. The breccia contains fragments of limestone, marl, shale and sandstone of Malm, Dogger and possibly Lias age. This is a fall-back breccia of fragments thrown up into the air and falling down into the crater. Shatter cones are present in the limestone blocks and planar features in the quartz grains of sandstones. These are characteristic of the lower degrees of shock metamorphism. However, there are no signs of the higher shock metamorphic effects, in particular melted rocks.

The Steinheim crater lies about 40km southwest of the centre of the Ries or about one crater diameter outside its rim. It also contains the eroded remnants of lake sediments of much the same character and age as those at the larger crater. It is therefore believed that the Steinheim and Ries craters were formed at virtually the same time by separate fragments of the same meteorite.

Itinerary *Thursday 13 and Friday 14 August*

The Ries and Steinheim craters were the first localities visited by the OUGS on the visit to Germany in August 1998. Having set off from Milton Keynes and stopped overnight at Rheims, the coach reached the Steinheim crater on the afternoon of Wednesday the 12th.

Time was pressing so the visit to Steinheim was restricted to the Burgstall. We looked at a quarry in brecciated limestone at the foot of the hill and then climbed up to the top of the Burgstall for a view of the walls of the crater and the central uplift.

In the evening we arrived at Nördlingen, within the Ries crater, where we were due to stay. This is an exceptionally well preserved, or heavily restored, mediaeval town which was used as a backdrop in the film "Willy Wonka and the Chocolate Factory". It has a complete circuit of walls and towers, which caused our coach to take a long time finding the only gap through which it could enter. Our hotel was the Kaiserhof, which had once been host to a group of American astronauts who had come to be shown the Ries in the hope that the rocks would resemble those they would find on the Moon. The hotel is close to St George's Church which is built of suevite. The party trooped up to the balcony at the top of the church's 90m high Daniel Tower for a view of the old town, the basement hills of the inner ring and the limestone escarpment of the crater rim in the distance (Figure 5).

Figure 5. Nördlingen walled town with the floor of Ries Lake and crater rim in the background.

Thursday morning began with a tour of the Ries Crater Museum. This was opened in 1990 to describe the impact event and its effect on the local landscape to the general public. We were shown round by Michael Schieber, the enthusiastic director of the museum and the main driving force behind its foundation. It is housed in one of the old buildings of Nördlingen but the interior has been remodelled to provide a spacious exhibition area. The tour begins with an introduction to the crater, including a huge copy of an aerial photograph in which the crater rim is picked out by a ring of clouds. The exhibition continues by describing the role of impact cratering on the surface of the earth and other planets and discussing the mechanics of cratering. Next, a series of rooms explain the geology of the Ries area before the impact, the impact event itself including some beautiful examples of moldavites and large blocks of Bunte Breccia and suevite and, finally, the infilling of the crater by lake sediments. The exhibition ends with a look at the economic geology of the Ries, including the use of the suevite as a building stone and cement additive and the history of scientific research on the origin of the crater.

For the rest of the day Michael took us on a tour of localities around the crater. The first stop was at Holheim, 4km south of Nördlingen (the localities visited are shown in Figure 1), where a hill of Jurassic limestone represents one of the megablocks which slid inwards during the crater modification stage. An abandoned quarry was used to display parallel grooves and striations on the top surface of the limestone, overlain by Bunte Breccia. The grooves were formed by abrasion of the limestone surface during the explosion but their resemblance to glacial erosion features was once taken as evidence for a glacial origin for the crater. On the way down the hill we passed the Ofnet Cave which is famous for the discovery of a nest of human skulls 7.5ka old. Another archaeological bonus was the remains of a Roman farm at the foot of the hill.

The next stop was at the nearby Altenburg quarry. Here the quarry face showed 20m of suevite with Jurassic limestone at either end. At one point a nearly vertical contact between suevite and limestone is prominently displayed. This quarry used to be interpreted as evidence for a volcanic origin of the Ries, the suevite being a tuff infilling a volcanic neck in the limestone. However, numerous borings in the quarry floor all found Bunte Breccia underlying the suevite and no sign of the limestone. The limestone outcrops must be displaced blocks. The quarry is historically important as the source of the stone from which St George's Church in Nördlingen was built.

The Wenneburg is a conical, partly tree-covered hill 10km east of Nördlingen. This hill is part of the uplifted inner ring of basement rocks marking the edge of the transient crater. A small old quarry exposes weathered rock with a schisty appearance. This is strongly sheared granite and amphibolite and includes a dyke of the rare rock type "Wenneburgite". On the east side of the hill we saw an outcrop of buff-coloured soft limestone which contains *Hydrobia* snails and *Cypris* ostracods. The limestone was formed in the brackish water of the Ries lake, growing on the foundation provided by the underlying basement block.

Figure 6. Suevite overlying Bunte Breccia in Aumühle Quarry.

The last visit of the day was to the Aumühle quarry which is just inside the northeast rim of the crater. This quarry has good exposures of the suevite, the Bunte Breccia and the contact between the two (Figure 6). The Bunte Breccia is a red/brown deposit, the red colour deriving from the Triassic material mixed in with the paler Jurassic rock. The clasts are up to 1m long, some of the larger blocks being tightly folded. The contact with the overlying suevite can be followed for about 50m; it is abrupt but undulates at steep angles over the 10m or so height of the quarry face. The suevite shows well developed "flädlen", flattened glass bombs up to 20cm across. A feature that attracted the party's interest was the presence of voids in the form of suevite-filled vertical cylindrical tubes 30-40cm in diameter in the upper part of the exposure. These are presumably gas escape structures analogous to the pipe vesicles of igneous rocks.

This marked the end of a very interesting day in the museum and in the field with Michael Schieber. The day's activities were rounded off socially when Michael, accompanied by Gisela Pösges also from the museum, joined us for dinner at the Kaiserhof Hotel.

On Friday morning 14 August, we left Nördlingen for the last time and visited the Otting Quarry just outside the crater rim in the east. The quarry has faces up to 19m high displaying the freshest suevite the party had seen. The suevite contains flädlen

up to 20cm across and clasts of basement rocks in various stages of shock, some with glass rims. There was a discussion of the conditions under which the various components of the suevite were formed. They are believed to have come from the deepest part of the transient crater at some 3km depth. Rob Hough recounted his work extracting diamonds from the suevite. These are in the form of clusters a few hundred microns across with hexagonal outlines and are probably pseudomorphs after graphite. There are also much smaller diamonds which may have condensed from the vaporised rock.

It was now time to leave the Ries. We had visited two classic impact craters and had a taste of their unusual geology. The next stage of our trip was to take us to see the other geological wonder of Bavaria, the Solnhofen Limestone and its fossils.

Will Jones

The Plattenkalk and its fossils *Friday 14th August*

Our visit to Bavaria gave us the opportunity to see the famous Solnhofen Limestone in the Southern Franconian Alb. The formation belongs stratigraphically to the Lower Tithonian (150 - 144Ma) in the Upper Jurassic. Lithologically the limestone is described as a plattenkalk meaning a flat lying calcareous rock, it is micritic and generally occurs in thin layers one or two centimetres in thickness. The plattenkalk appears to have been laid down in shallow lagoonal basins separated by sponge algal mounds. These features later developed into large reef masses in the west of the region. The shallowing of the waters in the lagoons was facilitated by the uplift of the South Bavarian Reef Platform which restricted access to the Tethys Ocean to the south. Thus, as water levels dropped calcareous sediments were deposited in the basins; under these conditions the plattenkalk developed fine lamination (as in the Solnhofen Lithographic Stone) consistent with a lack of benthonic fauna and a calm undisturbed bottom zone with high salinity. By contrast, the bankkalk, or normal limestone, would have lost its original lamination due to bioturbation in waters of normal salinity.

In the Solnhofen area the plattenkalk consists of flat bedded limestone (Flinz) with intercalations of finely laminated calcareous marl (Faule). Flinz is almost pure limestone (99% $CaCO_3$) whereas Faule has between 80 - 90% $CaCO_3$ plus an insoluble residue of clay minerals. Now these limestones are well known in the Solnhofen area for the amazing variety and exquisite detail of their fossil remains, hence Solnhofen is designated as a lagerstatte: a site of exceptional preservation. The question arises as to why the plattenkalk should contain up to 700 fossil species; a rich hunting ground for some of the 19th century palaeontologists!

The exceptional preservation of these species was partly due to the presence of hypersaline bottom waters; not muddy but clear where fine calcareous sediment was laid down under low energy conditions. Most creatures died as they sank into the stagnating brine, although some survived long enough to leave tracks on the lagoonal floor. But it was also the lack of scavengers that contributed significantly to the preservation of organic remains. There would have been few creatures left alive on the sea floor to scavenge the remains. Furthermore, rapid burial of the carcasses would be necessary to preserve complete specimens and this may well have been achieved as creatures killed during storm events suffered catastrophic burial by suspension fall out.

The palaeoenvironment appears to have been lagoonal in which the surface waters were of normal salinity but with anoxic bottom waters. When a storm surge took place coarser sediment would have been washed into the basins from the sponge algal mound-sand reefs, some of which may have formed islands in the lagoon. Shoreward currents on the surface would cause sub-surface currents in the opposite direction. Thus, the mixing of the waters between the hostile bottom zone and the oxygenated surface zone would result in the death of many benthonic creatures which would be swept from around the algal mounds into the basins.

The bulk of the marine organisms included squid, belemnites, fish and swimming reptiles plus planktonic creatures like jellyfish and stemless crinoids (*Saccacoma*); oysters attached to floating debris were also common. Moreover, there were numerous terrestrial organisms around the margins of the lagoons: land plants, dragonflies, lizards, small crocodiles, pterosaurs and archaeopteryx. These creatures would have been either washed in or blown into the lagoon during storm conditions.

When fossilised remains are discovered they are usually flattened. If the stone is split, the fossil is found preserved in a depression in the overlying slab with a corresponding mould in the underlying slab. Some of the best examples of exceptional preservation can be seen in local museums: the Jura Museum in Eichstatt and the Buergermeister Mueller Museum in Solnhofen. The following specimens are recorded to give an indication of the variety and preserved detail of the fossils found in the plattenkalk.

i) Horseshoe crab (*Mesolimulus watchi*) (Figure 7a). This creature had an armour plated head shield and two lateral insect facetted eyes with six pairs of legs to which claws were attached. Sometimes it left trails along the sea floor at the end of which the dead animal was found.

ii) Crayfish (*Aeger tipularitts*) (Figure 7b). A shrimp-like creature with a laterally flattened body armour and five thin pairs of legs and long feelers, all delicately preserved.

iii) Dragon fly (*Aeschnogomphus intermedius*) (Figure 7c). This specimen has a 10cm wing span and the delicate arteries in the wing are preserved in exquisite detail.

iv) Kugelzahnrisch (*Pycnodontus*). A large flat disc-shaped teleostean fish which lived in the coral reefs. Its strong teeth were capable of cutting and grinding shells for food. Tough scales arranged in a net-like pattern covered the body which grew up to a metre in length.

v) Angel Fish (*Squatina alifera*) (Figure 7d). A cartilaginous fish related to the sharks and rays. The fin structure and backbone up to 50cm long are beautifully preserved.

vi) Pterosaur (*Pterodactylus elegans*) (Figure 7e). This small flying dinosaur had a wing span of about 50cm with two long fingers and webbed skin between them. Its beak-shaped jaw contained sharp inward projecting teeth. This species had only a short tail and its ability to fly must have been somewhat limited.

vii) Archaeopteryx (*Archaeopteryx lithographica*) (Figure 7f). Undoubtedly the discovery of specimens of Archaeopteryx in the late 19th century made the Solnhofen plattenkalk geologically famous.

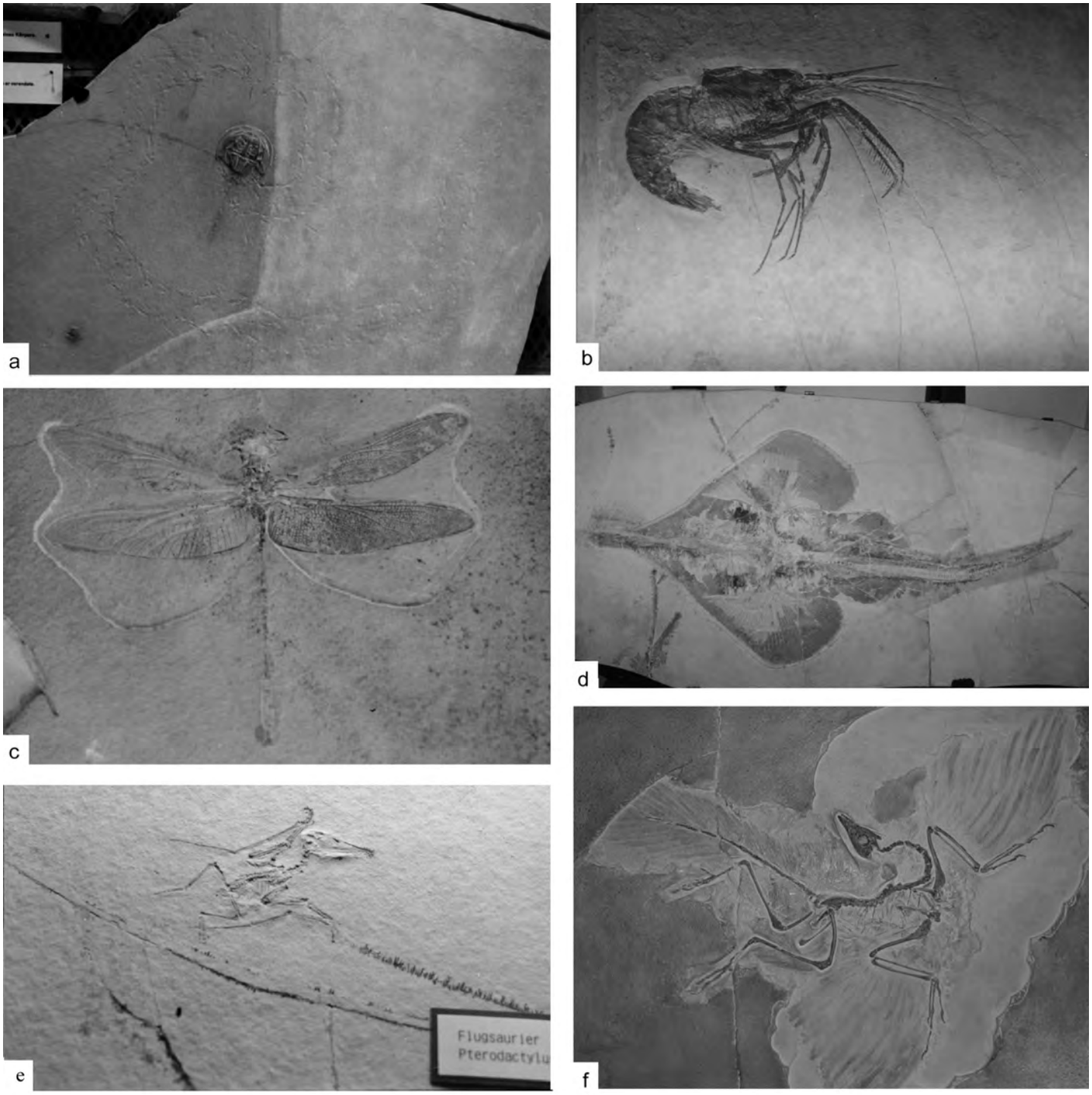

Figure 7. a) Horseshoe crab (*Mesolimulus watchi*); b) Crayfish (*Aeger tipularitts*); c) Dragon fly (*Aeschnogomphus intermedius*); d) Angel Fish (*Squatina alifera*); e) Pterosaur (*Pterodactylus elegans*); f) Archaeopteryx (*Archaeopteryx lithographica*).

Archaeopteryx is the earliest known bird which has reptillian features including a toothed jaw and claws on the tips of its fingers in the feathered wings; also its backbone continues down to the tail feather. Seven specimens have now been found in the region. One of the most complete examples was found near to Eichstatt and is now displayed in the Museum fur Naturkunde in Berlin.

John Downes

Bürgermeister-Müller Museum in Solnhofen

The fossils in this museum were originally collected by Freidrich Mueller, the former mayor of Solnhofen.

There were two showcases in the lobby of the museum to draw the visitor towards the main exhibits. The first showcase contained the leading fossils from the Cambrian to Tertiary which included trilobites, ammonites and crinoids. The next showcase was very striking as it contained ammonites from the Altmuhl region displayed in the shape of an ammonite (Figure 8).

A brief description explained that the Jurassic in this area is divided into the Lower or Black Jura (Lias - oily slate), Central or Brown Jura (iron-containing Dogger) and the Upper or White Jura (Malm). Above the Malm Limestone lie the layers of

Figure 8. Ammonites from the Altmuhl region.

Solnhofen Limestone. 150Ma ago great parts of Central Europe were covered by Jurassic seas. Near the shore there were lagoon-like shallow basins surrounded by coral reefs. Small-particled limy slime was deposited in these lagoons forming an ever-growing layer of lime mud. Dead animals and plants sunk into the mud and if covered quickly enough by more lime sediments they could not decay and were preserved. The single plates (Flinz) of Solnhofen Limestone can be very thin. We would receive a fuller explanation from Dr. Gunter Viohl later that day.

Exhibits

We saw wonderfully preserved vertebrates including Ichthyosaurs (Figure 9a), Pliosaurs (Figure 9b), Plesiosaurs (Figure 9d) and Pterodactyls (Figure 7e). Pride of place was given to replicas of several specimens of *Archaeopteryx*. The fish fossils were incredible in detail and included bony fish like *Caturus* and cartilaginous fish like the ray-like Angel fish.

Arthropods were well represented including crayfish and horse-shoe crabs. One really striking example even had the crab's last few foot-steps preserved. Other notable specimens included sand stars and ammonites but the really striking specimens were the "soft" animal fossils including the dragonflies and jellyfish. Animals with no hard parts are under-represented in the fossil record and the details of the fossil jellyfish were truly amazing.

An exhibition of lithography on the first floor showed that Alois Senefelder, the inventor of lithography, was looking for a cheaper alternative to copper plate printing. He used slabs of the very fine-grained Solnhofen Limestone which he covered with a corrosive film on which he wrote using wax, soap and soot. The background was etched away with aqueous nitric acid leaving the design standing proud.

Jura Museum, Eichstatt

We were greeted by the director of the museum Gunter Viohl who seemed very enthusiastic about our visit. Two globes in the foyer showed the present area covered by sea and the area covered by sea 140-150Ma (when the Solnhofen was being deposited) before the Atlantic was fully open. We paused briefly at the model of the Ries crater before moving on to the model of the Solnhofen basin.

The model showed an irregular sea floor bottom due to the growth of microbial sponge mounds building a carbonate platform, some growing into small islands. There were small patch coral reefs, especially in the East. Life was possible in the surface layer but organic production was not high and some crustaceans, ammonites and horse-shoe crabs could survive in the lime mat area. In the steeper rocky areas seaweed could grow and brachiopods, isolated sponges, sea urchins and coral fish could live.

Gunter explained some of the conditions that allowed the phenomenal preservation of fossils in the Solnhofen Limestone. The area was at a latitude of between 20° and 30°N. The occurrence of thermophilous organisms such as reef-building corals, pterosaurs and large insects indicates high temperatures. A relatively high degree of aridity can be inferred from the flora which displays many xeromorphic features such as thick cuticles and reduction of leaves to scales. Influx of fine sediment occurred during storm events which Gunter suggested may have been monsoonal. The lagoon had a restricted exit to the open sea so the salt concentration in the basin would result in a bottom hypersaline layer. The conditions on the basin floor would have been anoxic so there were no scavengers.

The key conditions for preservation were:-

1) an anoxic bottom

2) a supply of animals - monsoon storms from the SE brought animals into the basin where they were rapidly killed. Some benthic animals crawled along the bottom (leaving tracks that have been preserved) for a short time before succumbing. Pterosaurs, *Archaeopteryx* and insects were forced down by the storms and drowned.

3) rapid burial - the monsoon storm stirred up the lime mud bringing it into the basin covering the specimens.

Some of the specimens in this museum were very similar to those in the museum at Solnhofen and in an equally incredible state of preservation. Among the most striking were the ichthyosaur with stones in its stomach from one of the Bohemian islands and fossils capturing the last moments of life, e.g. the fossilized "footsteps" of horse-shoe crabs, the rollmark of an ammonite shell, the mark of an ammonite's tentacles, a shoal of 77 fish all killed in an instant, fish with prey in their mouth and wonderfully preserved jellyfish, grasshoppers and dragonflies. A 4m long marine crocodile (Figure 9c), the largest fossil found in the Solnhofen limestone is displayed here. Some unique specimens were on show, e.g. the Chinese birds (*Confuciusornis*) which were a little younger than *Archaeopteryx* at 120Ma (Lower Cretaceous). Apparently the way to determine if a feathered creature was able to fly is examine the symmetry of the feathers - to fly the weight of the feathers has to be asymmetric.

Our schedule was extended a little by Gunter's enthusiastic tour of the museum. We progressed eventually to the aquarium to see modern horse-shoe crabs and Gunter pointed out that it is not certain all the fossils of crabs were of the whole animal as they shed their hard exterior as they grow.

Maxberg Museum *Saturday 15 August*

After visiting the Solnhofen limestone in the field we visited the Maxberg Museum which had a display of lithographic plates and the prints produced from them. A reconstruction of a Roman bath with Solnhofen limestone flooring showed that the limestone has been in use for many centuries. Another replica, that of a South Bavarian monastery floor, showed various colours from the

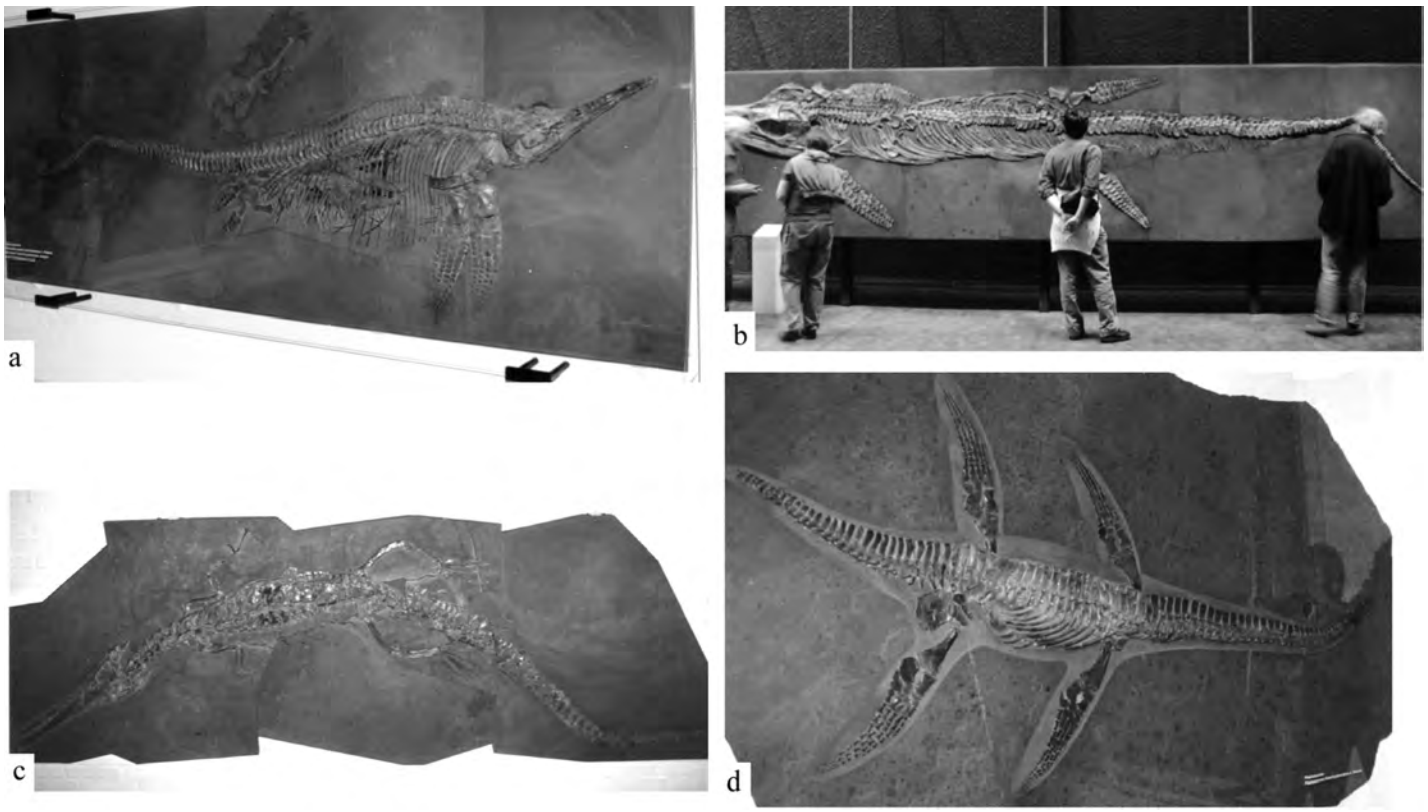

Figure 9. a) Ichthyosaur; b) Pliosaur; c) Crocodile; d) Plesiosaur

Solnhofen limestone and some stones, notably the red slabs from elsewhere.

The displays of dendrites and iron-staining in the limestone were very impressive as were the fossil specimens displayed. Inevitably replicas of the *Archaeopteryx* were also displayed (these old birds seemed to be everywhere) and Gunter told us about the mysterious disappearance of the Maxberg specimen that was in private hands and was never found after the death of the owner.

Marilyn Mayes

Idar-Oberstein *Sunday 16 August*

My excitement was hardly containable as we arrived at the twin towns of Idar-Oberstein. (These two independent cities have been joined since 1933). Ever since being smitten by the rock-bug and fascinated by lapidary and jewellery making, I had read about the wonderful precious stone capital of Europe and here, at last, a dream was coming true!

Driving through the streets we noticed the large globe-shaped fountain covered in huge slabs of polished agates and other semi-precious stones, and a town wall covered with a map of the world, encrusted with more polished stones. First impressions had not been disappointing.

The first close encounter of these "Edelstein" (gemstones) was at the Museum of Idar-Oberstein (Heimatmuseum), nestling at the foot of the Chapel in the Rocks. Here we found everything which made Idar-Oberstein famous. The Gemstone industry here was founded on the mining of agates, amethyst and jasper, which had crystallized in vugs in the Permian volcanic flows (Figure 10). The skills of the engravers and stone carvers were stunning. The miners from Idar were the first to go to Brazil and send amethyst and agate back to Idar-Oberstein for skilled working. In the museum were the largest specimens of minerals ever imported from overseas to any European country. Elephant sized amethyst geodes as tall as the room and smoky quartz crystals as big as tree trunks are some superlatives that sprung to mind. I even spotted a beautiful sample of haematite from Florence Mine in my home county of Cumbria. The Fluorescence gallery was the best I'd ever seen. This was just the beginning.

Next day we visited the Steinkaulenberg gemstone mine where agate was mined until the 19th century. There is a great deal of mineralisation remaining and as we wandered into the tunnels, amethysts, agates and crystals of smoky quartz sparkled in the pillars. The tunnels and galleries are situated in a nature reserve and the 10-minute walk from the car park to the mine is along a well-designed geological trail.

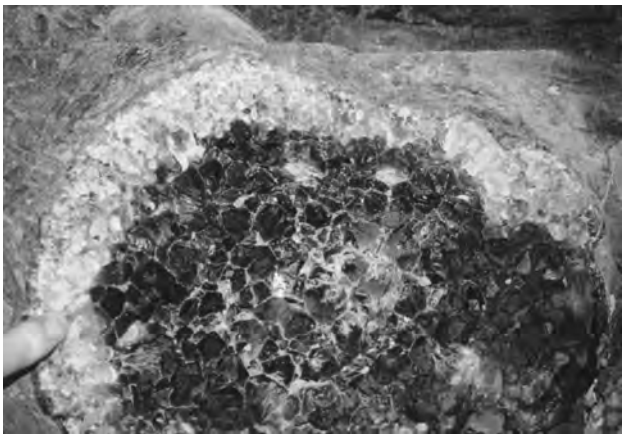

Figure 10. Amethyst geode.

Idar families had emigrated to Brazil and had found agates that were bigger, better quality and cheaper to extract. They sent these back to Idar to polish and cut. The town began to expand as a centre for gemstones and semi-precious material working. The mine closed in 1870 and all that remains are the traditional, handed down skills of working the stones that we had seen at the Heimatmuseum. There was an interesting display of stone cutting and polishing machinery. The various models showed workers cutting and grinding the gemstones; here the miners had to lie face down on a bench, hence the term "keeping your nose to the grindstone". The conditions for the old miners were dangerous and difficult. They worked in 1.2m tunnels at a rate of 1 man, 1 metre, in 1 year. The words of the seven dwarves kept springing to mind.

The 'edelstein' experience continued with a visit to the most concise collection of gemstones in the world at the German Gemstone Museum. Irvine had translated the town guide which truthfully described a "richness and diversity shown scarcely or never (elsewhere) in the world". There were so many facets to be seen among the 9,500 exhibits of cut and rough gems, and carved engraved gem sculptures that it was hard to take it all in.

After the agate mines had closed Idar developed an economy based on working and trading precious stones, which now also includes tourism. Germany's diamond and precious stone exchange (Bourse) in the centre of Idar ranks along with Hatton Garden, Amsterdam, Paris and Rio in the gemstone exchange industry.

After these displays of splendour we explored the twin towns. A mineral specimen and stone hunters' paradise. I was hot on the trail of some Lapis Lazuli and entered the Aladdin's cave of Mr Pashmani. Dave has been a long-standing customer and he kindly introduced me. With the Eastern consideration of customers he sat me down with a cooling bottle of water and described which mines the lapis had come from. Among other specialities were some beautiful aquamarine crystals, oh to win the lottery eh?

A richly fascinating experience, including some special lapis and other gemstones to try and fashion into jewelry or just admire are lasting memories of Idar-Oberstein. Definitely a visit not to miss if you want to see brilliant examples of Nature's riches used architecturally, in excellent museums and in shops to drool over.

Angie Marchant

East Eifel Volcanic Field *Monday 17 August*

A drive of some 90 miles initially through beech/pine forest over folded Devonian rocks of the High Hunsrück which are overlain by Tertiary sediments, brought us to Mendig where we were met by our guide for the day Dr. Klaus Schmidt, and greeted by Burgermeister Rolf Rösner.

The Laacher See Volcano

The Laacher See, which we glimpsed briefly, occupies a collapse structure formed on the site of an earlier maar, which resulted following the violent Plinian eruption of the Laacher See volcano, circa 11,000 (in some accounts 13,000) years BP. The amount of material ejected, about 5km^3 of lava and 10 km^3 of tephra, was greater than that resulting from the 1980 eruption of Mount St. Helens. During the three days of the eruption, the crater migrated from SW to NE; the Laacher See has the form of a figure eight. At the same time, the eruptive process varied to produce phreatomagmatic, surge and nuée ardente deposits. Air fall from a 40km high eruption column was deposited over a large area and has been recognised as far as northern Italy, and at a distance of 1,000km from the vent in the Baltic. The finest material remained in the upper atmosphere for a few years and probably had short term effects on the climate of the northern hemisphere, reducing temperature by at least 0.5°C.

The Laacher See Crater is surrounded by older scoria cones on which the more proximal Laacher See tephra was deposited. Among these was the Wingertsberg, a quarry which was our next location.

The quarry face, the "Wingertsbergwand", is almost vertical and about 10m high (Figure 11). It is composed of numerous layers of Laacher See tephra, the colour and composition of which reflect the various episodes of the eruption: surge, airflow and air fall. Some layers contain bombs in some cases with bomb sags and/or blocks of the sedimentary host rock. Changes in this material with increasing height of the face reflect both this varying eruption-type and the migration of the crater towards the NE.

Phenocrysts of feldspar and phlogopite were relatively abundant and of particular note were those of the characteristic mineral in these deposits, the beautiful blue haüyne.

Figure 11. Laacher See tephra at Wingertsberg Quarry.

Niedermendig Lava Flow

This flow is associated with the Wingertsberg scoria cone and thus pre-dates by many thousands of years the Laacher See volcano. Mendig was built on the lava flow both literally (the flow underlies the town) and economically through the stone and brewing industries.

Most of the quarries in the Niedermendig Lava Flow are subterranean but we were able to visit the Michels quarry which is at the surface. Here the flow is <5m thick and is overlain by Laacher See tephra. The basalt is columnar and vesicular. The bottom third is formed of thick basalt columns (1 - 1.5m diameter); the top layer consists of thin columns (usually <200mm diameter). The size and distribution of the vesicles varies according to their

vertical position in the flow. There were blocks with a heterogeneous distribution of numerous irregular vesicles.

The basalt has been quarried since Roman times; underground mining began in the 16th century. The vesiculation enables it to be sawn and dressed with chisels relatively easily and, being well crystallised, it does not break into flakes. We were able to see the basalt sawn and dressed at the small works of the Bous firm and to see some of the old equipment and finished products including millstones, paving, architectural carvings and sculpture at the nearby outdoor Museumslay ("lay" is an old local name for rock or stone). Millstones were a particularly important product of the underground quarries in the Niedermendig lava flow.

The extensive system of tunnels and chambers formed by the quarrymen within the flow (here 10m thick) took on a new function in the 1840's when a change in brewing technology required a constant storage temperature of 6 - 10°C. The Niedermendig mines provided ideal conditions and 28 breweries were established inside the flow. With the development of refrigeration in the 1870's these were abandoned, leaving just one, the Vulkan Brauerei (Vulkan brewery) in Mendig but it no longer uses the underground workings. 160 steps down brought us into the abandoned brewery still containing numerous storage tanks but now, unfortunately, empty. A short walk through the old brewery gave us some idea of the extent and formation of the flow and of its history. Back at the surface we returned to the present by trying the products of today's Vulkan brewery before our journey back to Idar-Oberstein.

Irvine Walker

Book reviews

A Revised Correlation of Quaternary Deposits in the British Isles by D Q Bowen (ed), 1999, BGS, 174pp, £39.00 (paperback) ISBN 1862390428.

The main object of this report is to describe, define and correlate the Quaternary deposits of the British Isles. The first edition was published by the British Geological Society in 1973 (Mitchell *et al.*) and it was based on the designation of British Standard Stages defined at 'type localities'. Correlations were then made with these type-localities for nine principal regions in the British Isles: namely Eastern England, English Midlands, Northeast England, Northwest England, Southwest England, Southeast England, Scotland, Wales and Ireland. The present report corresponds broadly with the nine regions used in the first edition but includes a chapter on the continental shelf surrounding the British Isles.

Subdivision of the Quaternary of the British Isles into a Pleistocene and Holocene Series has been standard for some time, but subdivision of the Pleistocene into Lower, Middle and Upper has not yet been formally proposed. This report, written by individual authors, mostly discusses the Pleistocene deposits with only an occasional mention of the Holocene stratigraphical units. It is subdivided into 11 chapters covering all the regions of the British Isles, their stratigraphical units and their relationship with other units which is a main tool in correlations. Each chapter has an informative introduction setting the scene for the deposition of glacial deposits in that particular region. The region is broken down into areas and localities with each locality then further broken down into formations, members and beds describing the stratotype to be found there. Each region has a map showing the approximate location of stratotypes and a national grid reference is included in the text.

Since 1973, the last twenty five years have seen an explosion of new data; new methods of geochronology confirmed that additional events were recorded in the Quaternary deposits of the British Isles. Some of the new methods include uranium-series ages, Thermoluminescence (TL), optically stimulated luminescence (OSL), election spin resonance (ESR) and amino acid dating of marine and non-marine organisms. D-alle/L-lle ratios provide a relative dating tool that form an important additional means of correlation (aminostratigraphy).

There in a excellent introduction to the report which discusses all aspects of correlation and classification of the Quaternary deposits, i.e. correlations with the climatic system, land-sea correlations using oxygen isotope stratigraphy, ice-rafted sediments, terrestrial deposits and deposits beneath the North Sea and all other relevant data. Detailed explanations of the problems encountered with correlation of glacial deposits and description of the methods used are discussed in the introduction and the editor is not afraid to admit the possibility that some methods may give anomalous results.

There are 32 correlation tables throughout the report, each one showing the Quaternary correlations and oxygen isotope stratigraphy in each region, and 8 regional maps. It is well presented, consistent in quality of writing and easy to read. The text is well supported by the correlation tables, maps and national grid references and the reader can dip in and out of any region to be able to relate to the correlations that are proposed.

However, it is not a bedtime read, and the editor has admitted that this report is rather specialised and not well suited to the needs of everyone. It is a good reference book and would be particularly suitable to those who have an interest in the Quaternary deposits of the British Isles, although at £39.00 it is rather expensive.

Margaret Bemrose BSc(Hons) Open, Interested Amateur

Palaeoweathering, Palaeosurfaces and Related Continental Deposits, Special Publication Number 27 of the International Association of Sedimentologists, by Médard Thiry and Régine Simon-Coinçon (eds), 1999, Blackwell Science, 406pp, £55.00 (paperback) ISBN 0632053119.

This book is published by the International Association of Sedimentologists and consists of a series of papers presented for the International UNESCO-IUGS Program. Throughout this series of papers, both physical and chemical approaches are addressed. Regional studies are presented from varied locations: Australia, India, France and Scandinavia. The various papers address palaeoclimatic studies and global changes. Simulated weathering conditions are compared to modern ones, revealing startling differences. A fresh approach is taken, looking at the whole palaeo-landscape.

The study of ancient weathering features often reveals profiles much thicker, and with unusual geochemical signatures, compared to present day landscapes. There is also clear evidence of weathering at different rates due to climatic changes: e.g. during the Cretaceous, granite weathered three times faster than the present day. Also, there is an insight into the effects of the rapid decline of CO_2 levels in the late Silurian/early Permian which coincides with the rapid diversification of terrestrial plants.

What I enjoyed about this book was the variety of approach; some of the detail is daunting, and obviously the result of painstaking and detailed research. Surely, this must provide a useful reference for the researcher and specialist in palaeosols but, even for the amateur, there is much to be enjoyed. I needed my Dictionary of Geology to hand to remind me of the importance of laterites and bauxites. However, I became more absorbed by the subject as I went on. Nevertheless, this is not light reading.

The volume is expensive as a soft-back, yet has a good index and could be a useful addition to a reference library.

Ellinor Morgan BSc (Open)

Field trip to Hawaii, 1999, led by Peter Francis & Dave Rothery

Anne Burgess, Dot Hill, James Jackson, Monika Jones, David Maddocks, Linda McArdell, Sue Nelson, Fred Owen, Dave Rothery & Malcolm Shaw

Introduction

A few years ago, Peter Francis gave a slide lecture to WH Branch of OUGS (about the time of the impending Iceland field trip). "You don't necessarily need to go to cold climates to look at volcanoes", he said. As a direct result of that remark, a party of 32 OUGS members joined me at Heathrow on a cold and grey Valentine's Day in February to fly to Hawaii. There we were met by Peter and Dave Rothery (with leis), who had flown out ahead to finalise preparations. It is to Peter and Dave that we owe this memorable, rewarding field trip. Their enthusiasm for the geology, their knowledge of the islands, generously shared, was such that for some it has generated a deeper interest and further studies in volcanism.

Dot Hill

This was Peter's trip. He it was who conceived it, or else was prevailed upon by Dot Hill to do so. When it became apparent that the numbers wishing to come would require two leaders, Peter kindly asked if I would become his co-leader. I had only been to Hawaii a couple of times before, but who can turn down the offer of a free trip to somewhere like that? I left the hard work of itinerary planning, arranging for Hawaiian colleagues to give us talks and/or join us in the field, and (where necessary) getting permissions to Peter; initially on the excuse that I had my own Oman trip to lead for OUGS and later because I was busy chairing the final stages of production of S260. However, I did spend a couple of pleasant lunchtimes with Peter and Dot, debating such important issues as how many islands to visit, and whether we should allow people any free (non-geological) time. Even harder work was undertaken by Dot Hill, dealing with enquiries from OUGS members, negotiating with travel agents, and (ably assisted by Linda McArdell) making sure we were all happy once we got there.

Thanks to a research trip I had to central America that ended a few days before the Hawaii trip was due to begin, I only spent one day of February 1999 in the UK, flying from Nicaragua to Honolulu without recrossing the Atlantic. Thus I arrived in Hawaii 3 days before OUGS. Two main advantages of this were (i) I was able to spend some time with Peter (who was also already in Hawaii) checking out some localities for the fieldtrip, and (ii) Peter and I were there at the airport to meet the party, and had a fine time bestowing a flower garland (lei) round everyone's neck and kissing all the ladies.

As for the trip itself, the descriptions that follow will show what a fascinating place Hawaii is. My most abiding memories will be sealed bags of dried fruit and crisps that had swollen alarmingly by the time we reached the top of Mauna Kea, sheltering from torrential rain on Kilauea by having our lunch down a lava tube, and Peter's awful jokes. One of my treasured possessions is a photo of myself and my old mate Peter wearing grass skirts (ever so kindly bought for us by OUGS - I'll get you back one day Dot) at the last night party (Figure 1).

Peter died suddenly and unexpectedly at the end of October 1999. I know he enjoyed the trip as much as I did, and would want to join me in thanking Dot, Linda and the others who assisted behind the scenes and all those who have written such lucid accounts of what we saw.

Dave Rothery September 2000

Figure 1. Dave and Peter preparing to hoola.

Honolulu, Oahu, *Monday 15th February*

At 0800 six intrepid members of the party were waiting outside the hotel for Thomas, the kayak instructor for the University of Hawaii who had offered to take us by kayak to one of the small off-shore islands of Mokula to look at dykes.

Getting to the beach involved driving across and through (by tunnel) the southern end of the Ko'olau Range of hills which are the eroded remains of the Ko'olau shield volcano – active between 3–1.5Ma. This is deeply incised with valleys on the SW side, which still retains the gentle slope of the original shield; the NE side, however, is a very steep scarp face where most of this unbuttressed side of the volcano has fallen into the sea. Its top drifted in and out of low cloud, but we got some excellent views of the "gable end" type of erosion typical of basalts, and the lush vegetation that covered the slopes.

Thomas taught us the theory of Kayaking while driving to the beach, the practical we were to learn *in situ*! The water was clear aquamarine and warm, the sky was blue, and it was easy to forget we had had only 6 hours sleep after a 20 hour journey from the UK the day before. There was a strong current between the two islands, but we landed safely and were soon exploring the dyke complex. First a wave cut platform where the paths of dykes could easily be traced, most parallel to the shoreline trending NW/SE, and consistent with the Ko'olau fault system, but there were others cross-cutting these in often snake-like contortions. Towards the centre of the island, which only rises about 10m above sea level, the material between the dykes looked very like a well-weathered tuff, with a green tone reminiscent of chlorite – but it could also have been a weathered basalt. We looked for layering to support the tuff theory, but found none, and inspected some weak chilled margins. Time pressed us to conclude our visit, and paddle back as we had a tight schedule planned for the afternoon.

Figure 2. Oahu. Diamond Head, Waikiki and Ko'olau Shield gentle slopes deeply incised with 'run-off' valleys from high rainfall.

The object of the afternoon's activities was to look at some of the Honolulu series of cones – post-erosional or rejuvenation volcanic events around the Ko'olau volcano on the SE tip of the island. Why these events occur at such a late stage in the life of a volcano is poorly understood; all were monogenetic events, and all are on the plains of sediments derived from the eroding shield. We started at the Diamond Head Crater (Figure 2), a huge tuff ring, impossible to see in any perspective from ground level, so we had to use our imaginations and the map!

Figure 3. Oahu. Hanauma Bay with the coral reef.

Next on the programme was Koko Head with views over Hanauma Bay (Figure 3). The bay is in the centre of Iheihelauakea Crater, which is now breached on its seaward side, a haven for fish who enjoy the sheltered environment of the coral reef now housed there. This is the southern end of the SW/NE trending Koko rift, which produced a number of vents, the northerly end of which is Rabbit Island some 2km off-shore. The next stop along this rift at Lanai Lookout, below Koko Crater, allowed us a really close look at the results of a series of phreatomagmatic eruptions that built a cone, now almost eroded by the sea exposing much of the internal structures. In fact it could have been two cones, the first partially eroded before the second started, as indicated by a sharp change of slope. At the base of the first, a huge piece of a coral reef and, in each layer, fragments of both coral and basalt blocks indicating the material through which the vent formed and ripped apart during the explosive events. The lithics ranged from 5mm to 250mm, the larger forming sag structures. One very thick flow was identified as a lahar; unlike the ash fall deposits this was homogeneous, with no lithic fragments. The topmost layer adjacent to the coast was of basalt; it is unclear whether this was the last flow that built the cone, as its top was a wave cut platform now 20m or so above current sea level.

The penultimate stop was Makapuu Point and a steep climb took us to the NE side of the point to look at the solidified remains of a lava tube, and a puzzle, because on first sight it was difficult to see what it was; a massive boulder-looking edifice when viewed from the seaward side, with several layers of rubbly bottom. On climbing up we had stopped to see a very vesicular flow, with a good sprinkling of olivine crystals, 2-3mm in some of the vesicles. Most unusual.

From the point we had good views of Rabbit Island, the remains of another tuff cone (eruption with water interaction), and Kaohikaipu Island, the remains of a cinder cone (dry eruption) adjacent to it, and in the distance the islands of Mokula, our kayaking destination; all very different kinds of volcanism, standing side by side with the eroding shield of the Ko'olau range on land.

Linda McArdell

Dykes and Dips, *Tuesday 16 February*

The tone for today was set at the outset by Peter's introductory remark, "If you have your itinerary with you it's not going to be all that useful."

Thus encouraged, we set off for the first location, the Punchbowl, another post-erosional tuff ring of the Honolulu series. The interior of the cone is now occupied by the National Memorial Cemetery of the Pacific with the graves of over 30,000 servicemen, over half killed during the Second World War. There is no parking or stopping, so we drove slowly past the ranks of graves and the marble memorial.

Following the Pali Highway, we noted the steep cliffs to either side on the way to the Pali Overlook, from which there is a splendid view of the north-eastern face of Ko'olau and the low-lying land to seaward. ('Pali' means 'cliff' in Hawaiian) From here we were able to see clearly the relationship of yesterday's dipping layers and today's cliffs: the whole north-eastern part of Ko'olau has vanished in one or more massive landslides into the sea, so what is now left is only a fraction of the original shield. Some believe that its former caldera, underlain by dense material, lies underneath the Kaiwanui swamp below the pali. In the rock faces we saw dykes, both aa and pahoehoe lava flows, and, further down the route of the old highway, scoria from later events.

Overheard at this location: Dave, "Nobody's asked me how old it is." Voice from the crowd, "OK, so how old is it?" Dave, "I don't know."

Figure 4. Oahu. Dyke swarms in Kapaa Quarry.

Figure 5. Oahu. Kapaa Quarry. Calcite and epidote filled vesicles in weathered basalt.

As we arrived at the next location, Kapaa Quarry, both Peter and Dave gasped in admiration at the magnificent dyke swarm exposed in the quarry walls (Figure 4). Apparently neither had previously seen this, which they described as a world class location. It is in the rift zone of the Ko'olau shield, and in places over 50% of the quarry face is made up of dykes, each about a metre in width. It has been estimated that the aggregate lateral displacement of the volcano by more than 7000 dykes was up to 5km. We noted that the lavas contained vesicles filled with later water-deposited calcite and epidote (Figure 5).

Manager David Moore welcomed us to the quarry, which produces 2.5 x 10^6 tons per year, mostly for building and road aggregates. More interestingly, we learned that the quarry also produces BTB ('Basaltic Termite Barrier'). This consists of fragments of about 4 to 8 mm, and is laid in a thick layer below new buildings. The spaces are too small for termites to get through, but the fragments are too big for them to eat!

The next stop was another dip: this time a lunch and swim stop at Kailua Beach, joined by a couple of turtles.

The journey to our next location was highly educational, including Hawaiian pronunciation lessons from our driver, Lola (Ko'olau is 'Koh-o-lau', not 'Cool-ow') and readings about Captain Cook from Dave. We took the Eisenhower Interstate Highway (Interstate? The next state is 2500 miles of ocean away!) to the Waianae Coast.

This is the arid and relatively undeveloped leeward side of Oahu, which made it easier to see the geology of Waianae, Oahu's other shield volcano. As we travelled along the coastal road, and at our stop by the Lualualei military zone (which houses a large nuclear arsenal), we noted the lava flows dipping gently eastwards, away from the sea, and we saw that, like Ko'olau, most of the Waianae shield is missing, having collapsed into the sea in similar massive landslides. Such collapses are typical of unstable Hawaiian shields, which have no lateral buttressing.

The final stop of the day was at Kaneana Cave, a long sea-eroded cave now several feet above sea level, with some dykes well exposed in the surrounding cliff face. At this location we could also see the development of coral reefs along the present shoreline, before returning to the hotel pool and the last dip of the day.

Anne Burgess and Malcolm Shaw

Oahu to Big Island Hawaii, *Wednesday 17 February*

This was to be our last morning on Oahu, followed by the transfer to Hawaii itself - the Big Island.

Figure 6. Oahu. Road-cut exposure of air-fall deposit.

We drove north out of Honolulu climbing towards the high point of Round Top. On the way up we examined a road-cut exposure of an air-fall deposit (Figure 6). The exposure was several metres high, represented a single event and was well sorted. The deposit was post-erosional from the Tantalus vent about 3km to the north, and very alkaline. In fact the silica content was so low - less than 45% - that no feldspars could form and unusual minerals such as hauyne, melilite and feldspathoids were present.

Figure 7. Oahu. Cemetery inside an old tuff ring, Honolulu, with Pearl Harbour beyond the airport.

Round Top was an excellent view point (Figure 7). Below us was the flat-bottomed Manoa valley, completely developed and including the University of Hawaii. Just beyond it was the rest of Honolulu, fronted by Waikiki Beach. To the left was the low angle of the Ko'olau shield leading down to the dramatic Diamond Head crater on the coast. To the right was Punchbowl Cemetery, like Diamond Head a recent, post-erosional feature. Further away to the right was Pearl Harbour and beyond it the skyline was formed by the low angle of the Waianae shield.

We descended to the University of Hawaii and went down five floors in an elevator in the multi-storey car park to view our next exposure. Only in the USA could you do such a thing. The car park is partly cut into a single massive lava flow, more than 25m thick, that floors the Manoa valley. It was pale grey, undersaturated and rich in sodium and potassium - yet more alkaline products from the Tantalus vent. Beneath it is a coral platform, confirming its post-erosional status.

Before lunch on campus there were two excellent lectures. The first, by Professor Steve Self, described the historic and present

day activity on the Big Island, setting the scene for the following week. The second was by Professor Pete Mouginis-Mark on remote sensing, mostly from satellites using various parts of the electromagnetic spectrum to gain real-time information from even the remotest areas.

By now we were keen to get to the active areas near the hot spot and our half-hour flight, "younging up the chain", took us past Molokai, Lanai, Kahoolawe and Maui with its enormous Haleakala volcano. Clouds partly filled its crater, big enough to swallow Manhatten, now known to be an erosional feature rather than volcanic.

As we approached the Big Island and the city of Hilo, our base for the next three days, the two huge snow-covered peaks of Mauna Loa and Mauna Kea, each over 13,000 feet, protruded up above the clouds. Were we really going to get right to the top of Mauna Kea tomorrow?

David Maddocks

Mauna Kea, *Thursday 18th February*

On our first full day on Big Island (Figure 8) and after a delayed breakfast due to the influx of a coachload of American tourists, we set off in a convoy of people carriers - four-wheel driven and fully automatic. As we headed out of tropical Hilo, we noticed a quite sudden change in the vegetation, which was permeated more and more by aa lavas, giving the terrain the appearance of really poorly ploughed-up fields.

We eventually made a brief pit stop at the base of Mauna Kea where there were vast tracts of pahoehoe and aa lavas, which were now being gradually covered by new vegetation and we could see the scoria cones on the lower flanks of the volcano. We climbed continuously for over half an hour on reasonably good road, at one point we were able to see the vast pall of smoke from Pu'u O'o , despite it being many miles away. As we ascended to about 3000m we stopped at a ranger station, where there were acclimatisation huts for the observatory scientists and the whole outfit formed part of a ranching concern - notices present warning of the dangers of 'invisible cows' and it was true - we didn't see any! We approached the summit of Mauna Kea around many

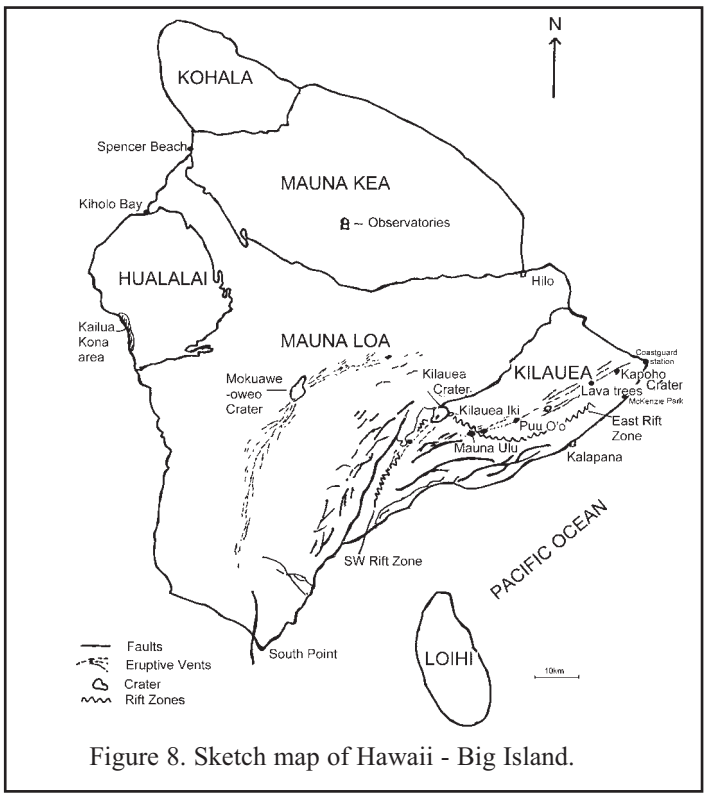

Figure 8. Sketch map of Hawaii - Big Island.

twists and turns in the road, snow covered parts of the sides of the various scoria cones which littered the flanks of the volcano. On arrival at the summit we could see the different observatories which are present - the Keck double being the most expensive - all making the most of the clear air above cloud level. We set off for the actual summit, a scoria cone - which apparently is the only real difference in height between this and Mauna Loa. The track comprised of small cinders but was not as much of a problem for walking as the altitude, which slowed down all but the most determined of climbers. After group photos against the most splendid of settings (Figure 9) we returned to the cars to descend to a site some 300m lower. Here most of the group followed Peter and Dave to look for glaciation features: they saw a tarn in a corrie, where there were superb striations, all carved out by a glacier

Figure 9. Hawaii. Most of the group at the summit of Mauna Kea at 14000ft, well above the cloud layer, with the observatories in the background.

during the last ice-age some 10,000 - 11,000 years ago - when Mauna Kea was capped with ice as opposed to the snow in present times.

The group tried to find the contact point between the aa lavas and the glaciated structures but failed. However, they were rewarded by seeing tear-drop shaped spindle bombs - some 1m long and 15-20cm in diameter. After lunching above the clouds we set off in descent to visit one of the scoria cones on the lowest slopes of the volcano. This had been quarried so we could see into the heart of the structure. There was some slight disagreement as to the position of the 'epicentre' of the cone but there were several intrusive dykes, inward-dipping and cross-cutting one another that were clearly visible amidst the tephra and cinder spatter. There were bombs with chilled margins as well as spatter flows. Most fascinating here was the huge 1935 pahoehoe lava flow, which had covered most of the visible landscape, flowing over earlier aa lavas, encroaching and breaching a long high wall, itself made of basalt rocks. There were several 'kipukas' present, where the lava, which was only about a metre thick had left pockets of land completely untouched.

Figure 10. Hawaii. Kamana Lava tube (it's not easy to photograph a black hole!)

The last visit of the day was to the Kamana lava tube (Figure 10), which was approached from the side of the road down stone steps leading to a beautiful plant grotto, partially obscuring the opening from the road. The pahoehoe lavas here were relatively thin, no more in some cases than 1m thick - thin enough for plant roots to penetrate and grow down to the floor of the tube to re-establish themselves. There were several episodes of lava flow, intermingling of both aa and pahoehoe. Thick chilled edges and very smooth margins were evidence for very fast flowing lavas, which showed diversional features too, as there were two funnels evident. At the apex of the convergence there were quite impressive entrail lavas. Some rock fall had occurred but it had not obliterated the presence of small stalactites, formed as a result of post-formational weathering. It was very hot once we returned to the surface but everyone agreed that it had been a most exciting, rewarding day.

Monika Jones

Kilauea East Rift Zone, *Friday 19 February*

A fine morning began with an essential shop for goodies to sustain us for another strenuous, sub-tropical day!

Stop 1: Lava Tree State Park

Driving south from Hilo we crossed the contact between the older Mauna Loa lavas, supporting sugar cane and macadamia plantations, and the younger Kilauea lavas, vegetated only by sparse, immature ohia forest. Moving further south-east we reached the crest of the east rift, where the higher rainfall encourages tropical rain forest to flourish, even though the lava supporting it erupted only 200 years ago (in 1790 from Halemaumau). That eruption produced some magnificent lava trees, preserved for posterity in The Lava Tree State Park.

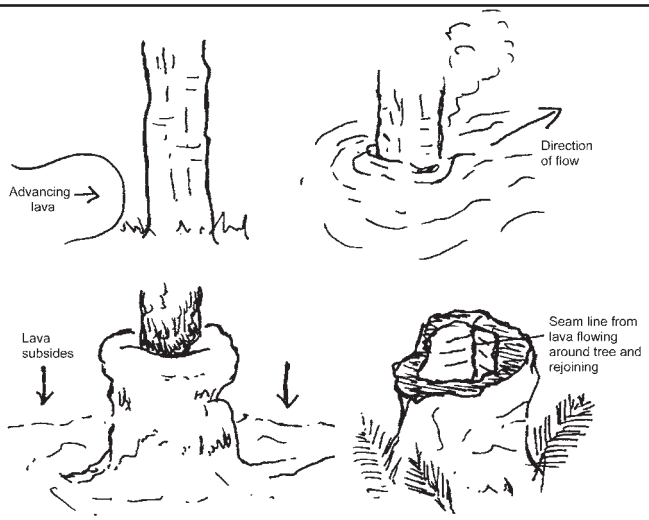

Figure 11. The formation of lava trees and flow direction.

Figure 12. Hawaii. Lava Tree.

They were formed by pahoehoe lava flowing round the tree trunks, partially solidifying against the cold bark to a height equal to the depth of the hot lava, which burnt the trees and left hollow, vertical basalt tubes (Figure11). Some display the bark pattern on the internal surface and the seam in the lava flow can be seen on the downstream side of the trunk as the two sides rejoined. When the lava level subsided the basalt mould remained as a lava tree (Figure 12). The original fissure from which the basalt erupted and flowed back down at the end of the eruption was evident near the park entrance.

Stop 2: Site of Kapoho Village

On 28 Feb 1955 a fissure 14km long developed along the east rift.

Figure 13. Hawaii. Puu Laimana scoria cone.

The easternmost end was near to the thriving, agricultural village of Kapoho, which was evacuated before 100 million m^3 of lava was erupted over 88 days. Kilauea immediately started to reinflate and after 5 years erupted again in the lower east rift; lava reached the sea in a few days. This time the village was destroyed.

A scoria cone, Puu Laimana, developed around the most active vent and produced fountaining 500m high. The present day scene here is dramatic. Along the rift numerous spatter and scoria cones and pahoehoe lava flows can be seen. Olivine phenocrysts could easily be found. The eruptive centre of the rift could be distinguished by the mass of jumbled lava without any flow structures (Figure 13).

Stop 3: Site of Coastguard Station, Kumukahi
Just before reaching the sea the 1955 flow engulfed the coastguard station, but spared the nearby lighthouse. A small section of the perimeter fence of the station could be seen below about 5m thick aa lava containing large rafts of pahoehoe lava. Again there was an abundance of olivine phenocrysts.

Stop 4: McKenzie State Park
This was our picnic spot by the sea!

Two interesting features here were the individual thick, blocky lava flows separated by red, scoriaceous layers seen in the eroded cliff face and a large circular hole formed by the collapse of the roof of a lava tube, complete with trees and other tropical vegetation still growing on the tube floor as though it had always been there. The hole, *ca* 4m deep and 5m in diameter, was so neat it could have been cut with a tin-opener.

Stop 5: Kalapana
Starting in 1986 the Kupa'ianaha vent on Kilauea erupted pahoehoe which flowed in lava tubes to the south coast near the town Kalapana. The lava was prevented from direct entry into the sea by a horst running along the shore. The horst diverted the flow eastwards towards the town, which was slowly engulfed and destroyed during the 5 year eruption. The lava covered about 4.5 miles of coastal road which has remained closed ever since (Figure 14). This stop is at the eastern end of the flow. Lava is currently erupting from Puu O'o vent and entering the sea at the western end of the flow, which was visited on Monday 22 and Tuesday 23 February.

Figure 14. Hawaii. 1990/91 flows from Kilauea covered the coast road and wiped out Kalapana village.

Here one becomes acutely aware of the scale of these lava flows and the devastation they can wreak on people and property. The top of the lava flow was *ca* 5m above the road surface and built 500m seawards from the existing shoreline, destroying a commercial coconut grove and a black sand beach in the process. Crossing the lava numerous coconut and coconut tree impressions were seen amongst the tumuli. The latter are large swellings of lava inside a plastic skin which forms within the chilled glassy outer surface of the flow as it cools. When the plastic skin bursts the outer, brittle crust breaks and fresh lava exudes from the crack forming entrail lava (Figure 15).

Fred Owen

Figure 15. Hawaii. Cracked surface of tumulus.

Hilo, Hawaii, *Saturday 20 February*
Hilo is the wettest town in the whole of the United States – a result of the Easterly Trade Winds – so we should not have been surprised when it started raining on Friday evening and that it was still doing so on Saturday morning.

The drive up to Kilauea Caldera (1350m) saw no change in the weather, and it was easy to understand why there is a fern forest on the eastern flanks of the volcano. Our first stop was at the National Park Visitor Centre, where a small exhibition explained the various aspects of Kilauea and its volcanism visible to the visiting public, with a cinema showing videos of some of the dramatic recent eruptions.

We moved on to the Hawaiian Volcano Observatory (HVO), and got our first glimpse of the Kilauea Caldera with Halemaumau Crater within it just visible in the distance. The Visitor Centre shows the history of the HVO. It was founded in 1912 by Dr Thomas A Jagger to study the lava lake that had existed in Halemaumau since 1905. Seismographs were housed in a wooden shed on the edge of the Kilauea Caldera. Today the HVO is part of the United States Geological Survey (USGS), monitoring volcanic activity on and around Kilauea, using the full range of modern techniques available. We had a visit to the monitoring facility planned for Monday, as guests of the USGS; today we were just tourists. Outside, the caldera was gently steaming from its many cracks, due to rainwater seeping into warm crevices.

Optimistically we headed off down the Chain of Craters Road, on the SW side of the volcano, but the cloud base here was still very low and visibility poor; a stop at the Ke Ala Komo Picnic shelter on the Holei Pali overlooking the scarp to the SW illustrated very clearly that we could have been anywhere – anywhere with horizontal rain that is! So a lunch break at Volcano House was proposed – hot drinks and a chance to dry out! Volcano House, now an hotel, was the original location of the HVO. Many old photographs are on display, charting the history of Kilauea since 1900.

In an attempt to outrun the rain we went to South Point, the most southerly point in Hawaii, (and also in the USA). We stopped briefly to examine a small finger of the 1868 aa flows from Mauna Kea near Kauahaao. This flow is the lowest flow (in elevation) from Mauna Kea in recorded history. It was particularly olivine rich, and a few chunks were collected with olivine crystals occurring singly in very vesicular lava – not dissimilar to the boulder we had seen on Makapuu Point on Oahu. Then on to South Point, where miraculously it was not raining. To the west, the Kahuku fault scarp (evidence of a massive landslip into the sea), where most of the 1868 lavas had followed its line, and a littoral cone made as the flow entered the sea. To the east, coastal plains with red clay soils of laterite, weathering products from Mauna Loa. The vegetation was very poor, which is probably due to the emergence of the Pu'u O'o cone to the east in the summer of 1983 and the resultant fumes and acid rain – the prevailing wind here being from the east. We had an hour to look around, so some of us attempted to walk to "Green Sand" Bay (round trip 7 miles). We didn't reach the named "Green Sand" Bay, but after half an hour descended to the nearest beach to collect some "sand" before returning, this proved to be about 30% olivine, 10% coral fragments and 60% basalt grains. The coastal section here showed two distinct layers of weathering products, overlying some coral, although it was impossible to see whether the coral was *in situ*, or a loose block that had been beached.

Linda McArdell

Kilauea Caldera, Crater Rim Drive and Thurston Lava Tube *Sunday, 21 February*

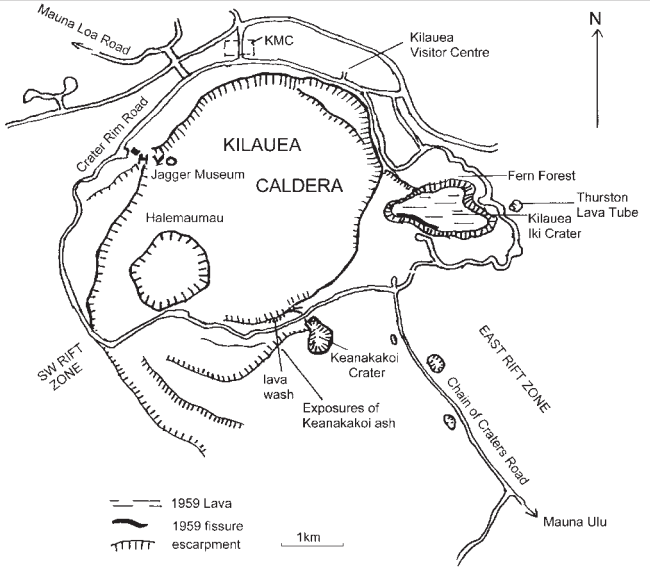

Figure 16. Hawaii. Sketch map of Kilauea Caldera and Crater Rim Road.

Undeterred by overcast skies and intermittent rain we set out from our base at Kilauea Military Camp (KMC), onto the Crater Rim trail for a closer look at the craters contained in and around the Kilauea Caldera. Kilauea, the youngest of the island's five volcanoes and still in its tholeiite shield stage is the closest to the 'hot spot' and therefore still active! The large depression at its summit 5km across qualifies it as a caldera, a collapse feature, formed from frequent rapid infillings and renewed collapse.

At the Jagger Museum results of geodetic and seismic studies have revealed a plumbing system made up of a sponge-like network of sills and dykes fed through a series of conduits by magma from the hot spot, 40-60km in the mantle below. Eruptions at the summit and into the two rift zones (east and southwest from the caldera) are created by the arrival of new magma increasing the pressure inside the magma chamber, 2-7km below the surface.

Beginning our trek on Crater Rim Road at the SW tip of the caldera (at the upper end of the SW rift zone) we crossed a number of large fissures created by earthquakes, fresh lava flows and pyroclastic cones before descending to the floor of the caldera. There, we walked among numerous yellow sulphur-deposited fumeroles towards Halemaumau crater - 'The Firepit' where an active lava lake once existed. Halemaumau is sacred to Hawiians. It is the home of Pele, the fire goddess. (Rumour has it that a member of the HVO staff found a bottle of gin there - intact, to which no-one would admit bringing to appease Pele). Ejection debris, large angular blocks weighing several tons from explosive eruptions in 1924, littered the rim. The blocks had been forced up from the plumbing system and collapse of the walls of the crater, as the magma drained out of the conduit leaving behind a 1000m-wide pit crater as deep as the Empire State Building. Further phreatic explosions had followed producing further blocks, lapilli and dust. We didn't linger too long watching the white clouds of steam emanating from the crater due to the smelly sulphorous air.

From Halemaumau, we crossed the pahohoe lava flow that had erupted from a 1982 NE-SW fissure towards the south end of the caldera wall. Each lava flow we had noticed had its own characteristics, its own signature and this one was no exception. "Like a baked meringue" someone said, very glassy, crusty and crunchy. It was incredibly easy to descend into a hollow beneath that thin shiny crust. We were glad of our sticks and gloves. Exposures in the south wall revealed fine-layered pumiceous ash, accretionary lapilli-ash, bombs and sags - the Keanakakoi Ash deposit produced by a catastrophic phreatomagmatic eruption in 1790 which killed many Hawaiians (Figure 17). On the surface ledges of the wall we found Pele's Tears, shed from tiny droplets of lava, fallout from Kilauea Iki (little Kilauea) just over the south rim. Tidemarks along the wall of the caldera betrayed the varying floor levels as they had risen or collapsed with infill or depletion. Subsequent collapse after the 1790 eruption formed part of the caldera that we see today.

Continuing round Crater Rim Road we drove towards Keanakakoi, one of two satellite craters, at the end of the chain of pit craters but situated in the upper part of the east rift zone. A lava-sloshed gully, formed by lava flowing down an existing erosional channel lay between the caldera and Keanakakoi. We could see where lava had splashed up the sides as it swam round the bends before draining out of the gully and onto the caldera floor.

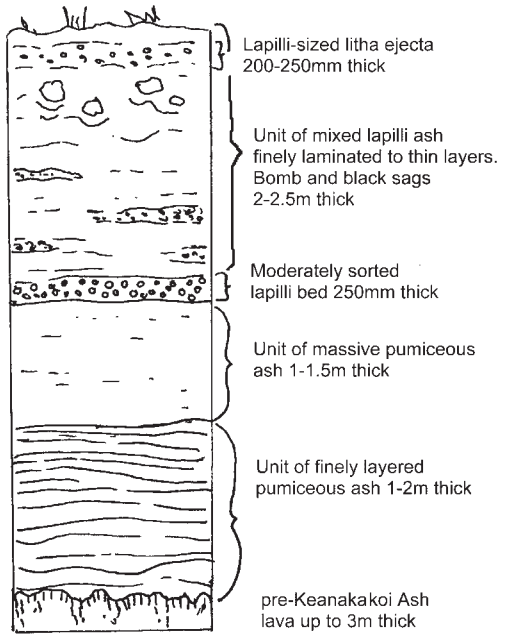

Figure 17. Hawaii. Keanakakoi Ash stratigraphy.

Hot pahoehoe lava had plastered the walls. Subsequent measurement and its position have determined its high speed and low viscosity.

We had one more crater to visit, but needed somewhere less exposed to eat our lunch. Persistent rain (12 inches of rain in three days) forced our leaders to rethink the itinerary. Hence lunch was eaten in the Thurston lava tube, which happened to lie east of Kilauea Iki, the crater we were to explore next. We found the entrance through rain forest tree ferns at the bottom of a shallow pit crater, one of the satellite craters formed during the collapse of Kilauea Iki. Following the well-lit tourist trail for part of the way we continued on through the rest of the 120m unlit, until we were literally on our stomachs. Our torches illuminated the eerie darkness; we could see rootlets, lava stalactites, wall-washed bench marks and the glassy surface of remelted lava (Figure 18). Drips

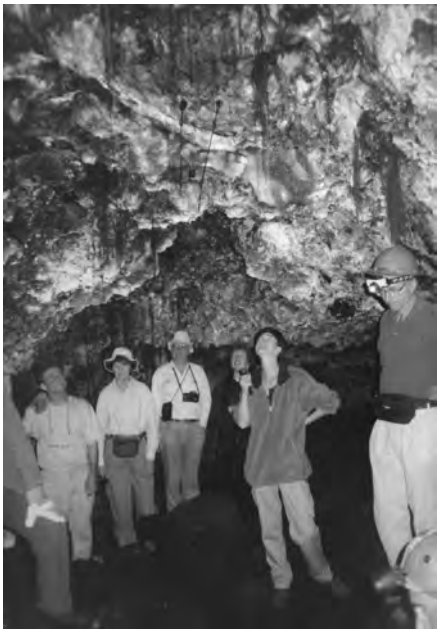

Figure 18. Hawaii. Rootlets hanging from the roof of the Lava Tube.

Figure 19. Hawaii. Kilauea Iki crater floor, it steams - due to the rain, and is still warm after 40 years!

of water echoed around us. It was wonderful. Collapsed roofing prevented further penetration but the lava tube, produced from one of the many pahoehoe flows that were erupted from Ai-La'au, is a couple of miles long.

Kilauea Iki (little crater), the other main satellite crater, could only be reached by descending 320m on a winding narrow path through fern trees and rain forest until suddenly we were right down, deep into the crater. Walking across the solid lava lake was magnificent, surrounded by high crater walls with little plumes of water vapour steaming from the floor (Figure19). Occasional and large angular blocks were seen on the floor, narrow cracks were plentiful and there were abundant olivine phenocrysts. We walked around tumuli, marvelled at a ring of tidal marks on the walls from where the lava had reached some 15m above before sinking down again. The lava here was about 40 years old and more than 60m thick, but the floor was devoid of vegetation. Kilauea Iki was responsible for the destruction of Kapoho, Koa'e and the south coastguard station and, in its precrater days as a lava shield (Ai-La'au), for the formation of the Thurston lava tube.

Some decided to walk the whole circuit of the crater and some were content to marvel at the features around us. Captivated by all that we had seen, we were nevertheless pleased to reach the comfort of our cabins, log fires, and dry clothes at the end of the day.

Dot Hill

Hawaiian Volcano Observatory, *Monday 22 February*
It was still raining on "Mauna Soaker" as we all piled into the small lecture room to hear the Monday morning briefing by the staff of the Hawaiian Volcano Observatory headed by Don Swanson. Sadly we learned that there had been a pause in volcanic activity during the past fortnight apart from an occasional breakout. The active bench at the ocean entry filled the bay and measured approximately 750m x 50m deep and was overdue for collapse. Handy to know!

Christina Heliker explained how the eruption of Kilauea started in January 1983 from the main vent of Pu'u O'o and is the longest rift zone eruption in historical time. The initial fire fountains reached an incredible 150m in height, the activity then switched to Kupaianaha where steady and destructive flows of pahoehoe moved SE to destroy the township of Kalapana and 7-8 miles of highway. In early 1992 the rift between Pu'u O'o and Kupaianaha froze up so that the lava levels rose in the Pu'u O'o vent and overflowed the crater walls and out through flank vents. Lava is still reaching the ocean but is mostly tube fed.

Paul Okibo then outlined the seismic monitoring programme. There are 65 seismic stations on the Big Island, most of them around the active areas. The signals are relayed back to HVO from the geophones via an FM radio telemetry system. He showed us sample trace patterns and explained how to interpret the signals.

Jeff Sutton described how volcanic gases from the various vents were collected and analysed. One method is to drive downwind of the vent with a correlation spectrometer (COSPEC'). By recording the speed of the car and the wind, a cross-sectional value of the sample can be calculated in tonnes per day. Levels have been as high as 100-150T but presently are about 50T and rising. CO_2, SO_2 and water vapour are the main gases emitted from the fumaroles. CO_2 is exolved directly above the magma chamber and the bulk of the SO_2 from the East Rift zone. The topography and the Trades combine to carry the gas cloud, known as "vog", south and around to the Kona coast. The local populace is warned when emission levels are high. It was interesting to learn that 0.25T per day is considered an illegal discharge in industry, punishable by law. The East Rift has produced over 2000T per day. If that is not enough, the gas produced as the lava combines with sea water at the ocean entry produces hydrochloric acid with a glass etching pH value of 1.2!

Mike, another member of staff, completed this series of very interesting lectures, briefly explaining how the inflation and deflation of volcanoes is measured using tiltmeters, dilatometers, GPS and radar interferometry. Current measurements show the south side to be sliding seawards at $7cmyr^{-1}$ and the relative plate motion around $9cmyr^{-1}$.

In conclusion, Don Swanson emphasised the close links his department has with the Civil Defence, but that sometimes their work creates problems for the population, as in the case where a map showing the high risk areas reached the public domain – house insurance premiums increased dramatically.

We were invited to wander through the corridors of the HVO to see some of their work in progress.

By lunchtime the rainfall was reaching record levels – 30cm in 48 hours – so the scheduled itinerary was abandoned and we split into three groups. One to Hilo to browse the Borders bookshop, the second to continue with underwater geology and the third went on a successful search for sun, sea and green turtles on Honuapo beach.

Dusk saw us assemble at the road end to watch the glowing steam cloud coming from the littoral cone at the ocean entry about three miles away and to see our first and, as it transpired, our last sighting of lava flowing from a breakout on the pali.

Sue Nelson

Mauna Ulu, *Monday, 22 February (afternoon)*

Those of us continuing with 'underwater' geology volunteered to walk up Mauna Ulu and Pu'u Huluhulu southeast of Kilauea, flanking Chain of Craters Road. The hike to this spatter and lava cone was littered with lava trees, a surreal landscape in the grey wetness. A more viscous and treacle-sticky lava had enforced moulds of trees through its advance, the direction of flow being easy to spot. Little ferns and other embryos of foliage were bursting through the cracks, bright green and yellow against the grey,

Figure 20. Hawaii. Descending Mauna Ulu with the cinder cone Pu'u Huluhulu forming a kipuka in the background. (A kipuka is a small area of land totally surrounded by recent lava, and isolated from other areas of biologically active land. Isolated species evolve genetic variations from adjacent and similar land.)

struggling to survive in the acidic air; kipukas, islands of older vegetated lavas surrounded by new added to the scenery.

We continued to hike from here, over the saddle between the cone and the lava shield which was Mauna Ulu (Figure 20). We passed a pool of hardened lava before reaching the crater's edge of M Ulu, unable to see into it for the wind blown steam and rain. A fissure had broken the crater's unstable edge, and lying among the cracks and crevices were small wind-blown florets of sponge-like reticulite and strands of Pele's Hair. By 1974, M Ulu had produced the greatest and most sustained single outpouring of lava recorded.

We, unlike our other colleagues, hadn't escaped the rain, but it had been worth it.

Dot Hill

Walk to the Ocean Entry, *Tuesday 23rd February*

After three days of torrential rain our expedition to the "Ocean Entry" was finally on. Hawaiian pahoehoe has a uniquely glassy surface and if the flow was gaseous, the surface shattered when walked on and could be very dangerous, even in dry conditions, so something we could not attempt in the wet. Pu'u O'o has been erupting effusively for about fourteen years, and is the most continually active cone known in the recent history of Hawaii. Its lava field fans out from the cone, about six miles from the sea on the southern flank of Kiluaea to a width of about twelve miles at the coastal edge. The coast road has been mostly obliterated by these flows, all that remains are short isolated stretches surrounded by the lava (Figure 21).

Figure 21. Hawaii. Remnants of the coast road.

Figure 22. Hawaii. Ocean entry - billowing steam marks the place where red hot lava meets the cold sea and rolls down the beach with the waves.

The current ocean entry was about three and a half miles from the western edge of the lava field. Flows from Pu'u O'o had been intermittent during our visit, but it was flowing now. A drive to the current "road end" in the dark the previous night had shown bright orange glowing patches on the scarp, where windows had formed in the lava tube, and a warm orange glow on the underside of the steam plume where the hot lava was flowing into the sea. In daylight all that could be seen on the scarp were wisps of steam from rainwater percolating through the surface near the hot lava tube.

Suitably clad in strong boots, long sleeved shirts, trousers, leather gloves and fluorescent vests, we set off. It is a tough surface to walk on, a bit like a deeply ploughed field that has frozen solid. There were also ample small fissures and tumuli to negotiate - the latter looked like well risen crusty loaves. Walking sticks were a definite advantage. Golden shards of "Pele's hair" glinted in the cracks, it is a fibreglass-like material formed when molten lava thrown in the air catches a strong wind.

Figure 23. Hawaii. Pahoehoe lava on the active bench. This print won prizes for Linda from both OUGS and GA photograph competitions.

Figure 24. Hawaii. Active lava bench with unusual 'crumpled black satin' texture. Extinct littoral cone in the distance; old sea cliffs middle and far distance on skyline.

The ocean entry was marked by a billowing plume of steam, and a small cone of rubble (littoral cone) that had accumulated as the molten lava had met cold sea water and shattered and spattered (Figure 22). Another littoral cone, now extinct, could be seen further to the east (Figure 24). Arriving at the far side of the ocean entry, it was quite likely that we had crossed over active lava tube several times as it meandered across the coastal plain to the sea, because occasionally the surface heat and humidity could be detected very strongly.

The old sea cliffs were close by and the new lava had overflowed and formed a hard surface (bench) on top of the old beach below. The flow had left the sea cliffs looking a bit like the side of an old bottle where candle wax had dribbled down. The littoral cone impeded the view of lava flowing into the sea, but a walk to the edge of the bench gave some views of lava rubble rolling down the beach with the receding waves. However, it was impossible to see into the end of the littoral cone to view the lava directly, a boat would have been necessary for that. The fresh lava of the bench was even more spectacular than that seen on the walk across the lava field – rope-like coils (Figure 23), fans, "tree root"-like oozes, "crumpled black satin" (Figure 24) (" " my invention). These benches are inherently unstable, lying as they are over wet basalt sand on the top of a very steep slope. The visit to the edge was necessarily short – it was chilling to learn that ten days later the whole bench broke away and disappeared into the sea, along with the littoral cone. The flow, however, continued.

Linda McArdell

Rest day, *Wednesday 24 February*

Hualalai shield, *Thursday 25 February*

After a well-earned rest day and with suitcases packed and stored at Kona Seaside Hotel, we set off for our final day of geology on the Big Island.

From the Kailua-Kona district we travelled north along Queen Kaahumanu Highway to a unique location, not only to Hawaii but also the world, on the north west flank of the Hualalai shield to view the large array of nodules within the Ka'upulehu lava which was erupted between 1780-1801.

The lava is an alkalic basalt and flowed at a rapid rate down the shield north west towards Kiholo Bay. The nodules displayed at

Figure 25. Hawaii. Olivine nodules within the Ka'upulehu lava.

Figure 26. Hawaii. Spencer Beach.

the surface were torn from the walls of the vent some 5-6 km away and carried along in the flow (Figure 25). They are coarse grained with interlocking crystals, mostly dunites (almost pure olivine), but also found are pyroxenites and some gabbros. All the nodules are crustal in origin and not from the upper mantle.

The terrain to reach the nodule locality was difficult to negotiate and consisted of aa and pahoehoe flows down a 10° gradient.

From there we continued north along the highway by minibus to examine a trachyte lava flow at the foot of the Pu'u Wa'awa'a trachyte pumice cone. This flow is of a type peculiar to Hualalai and is approximately 105,000 years old. The rock itself is characterized by the presence of blade-like feldspar crystals within the alkalic basalt.

The rest of the day was really a brief tour of the northern and oldest volcano on the Big Island, Kohala, which has not erupted for about 60,000 years. We travelled along the Kohala Mountain Road which runs through Cattle Ranch land and just south of the summit. During our lunch stop we examined an exposure of Benmoreite which displayed hornblende crystals, dark and elongate, some 3-4mm long.

From there we wound our way back south along the west coast of the island to Kona airport, with a brief stop at the Spencer Beach, and then it was time to collect our bags and return the minibuses before the long journey home.

James Jackson

Book reviews

Sedimentology and Sedimentary Basins: from turbulence to tectonics by Mike Leeder, 1999, Blackwell Science Ltd, 592pp, £35 (paperback) ISBN 0632049766.

It is at least ten years since I studied S338 (Sedimentary Processes & Basin Analysis) and some revision was long overdue. This book looked to be just what I needed to help me revise, extend and update my knowledge of things sedimentological. I was not disappointed: this book lives up to its subtitle, taking the reader from the fundamental physics and chemistry of sediments through to sedimentary basins and beyond.

After a short introduction, Part 2 covers the origin and types of sedimentary grains and comprises a useful geochemically focussed discussion of weathering and of organic and inorganic precipitation. Unfortunately I encountered a number of factual and editorial errors in this section, which detract from an otherwise excellent presentation.

The three chapters of Part 3 cover sedimentological fluid dynamics. They provide a smooth progression from ideal fluid flow through real world fluid flow to the behaviour of sediment grains in fluids. Much of the text in this part has been well proofread, but I found a number of errors and inconsistencies in the more mathematical parts. This is rich, fundamental material which needs to be studied rather than skimmed through; it forms the basis of our understanding of sediment transport and sedimentary structures covered in Part 4.

Part 5 covers the external controls of climate, changing sea level and tectonics on the production, transport and deposition of sediments. It provides the groundwork for Parts 6 and 7, which concentrate on sediment deposition in the various continental and marine environments. Part 8 discusses the variety of sedimentary basins that arise in different plate tectonic environments. These latter parts of the book contain much useful information and were relatively free from errors.

Overall, this is an excellent book that is marred by a large number of errors that should have been corrected during proofreading. On the positive side, the production of the book is excellent with an expanded table of contents and a good index. Diagrams are clearly drawn and the text is well illustrated; as a bonus there are a set of 17 colour plates. At the end of each chapter there are recommendations for further reading. Finally there are over 50 pages of literature references. This is not an elementary textbook; it would be of use and interest to anyone studying earth sciences at third level and beyond.

Duncan Woodcock BSc Hons (Open)

The Deep Hot Biosphere by T Gold, 1999, Springer-Verlag, 235pp, £19.00 (hardback) ISBN 0387985468.

An increasing body of evidence suggests that the surface and shallow-marine life of our planet is complemented by forms of life which inhabit seemingly inhospitable environments. Rich and varied flora and fauna are formed around black smokers, submarine volcanic vents through which noxious substances are emitted. Gold theorizes that beneath the surface of the Earth is a rich and diverse biosphere of organisms which rely on the oxidation of hydrocarbons to survive and flourish. His view is that life on Earth originated beneath the surface, and only colonised the surface when conditions became favourable for photosynthesis to develop, with the presence of liquid water, the termination of heavy bombardment by asteroids and a substantial reduction in harmful solar radiation.

Gold provides a plethora of "evidence" to support his theory, but much of this is both superficial and circumstantial - an unconvincing argument. Some of the sources which I tracked down proved to be insubstantial and inconclusive, and are only speculations. It is a good book to while away a long flight or train journey, but I remained as unconvinced about the deep, hot, biosphere as I am about the Bermuda Triangle.

Linda Lane Thornton MA and continuing Earth Science student

Alpine starts and afternoon nappes

OUGS Severnside and South West Branches' excursion to the Western Alps July 2000 – Leader Dr William R Fitches

Linda Fowler, with contributions from Isa Adams, Philip Clark , Martin & Jenny Elsworth, Ted Smith & Rob Tripp

A group of OUGS members travelled from the UK for a 10 day, three-centre excursion to the Western Swiss Alps. Two members of the newly formed Mainland Europe Branch also joined us for short periods, Isa from Germany and Annette from Switzerland. The majority of the group flew from the UK to Geneva, and then drove past Lac Leman and up the Rhône Valley to Martigny where they met others who had come by train or car. Some stayed in hotels whilst the rest camped. The Transalpin Hotel at Martigny was conveniently near the motorway and town, whilst the campsite had the advantage of being about 30 minutes (and 1000m) nearer the field locations for the first 3 days. It was reached via a winding mountain road from Martigny, through Salvan, to Van d'En Haut.

During the first three days we looked at the geology of the Helvetic, or External, Zone (Figure 1).

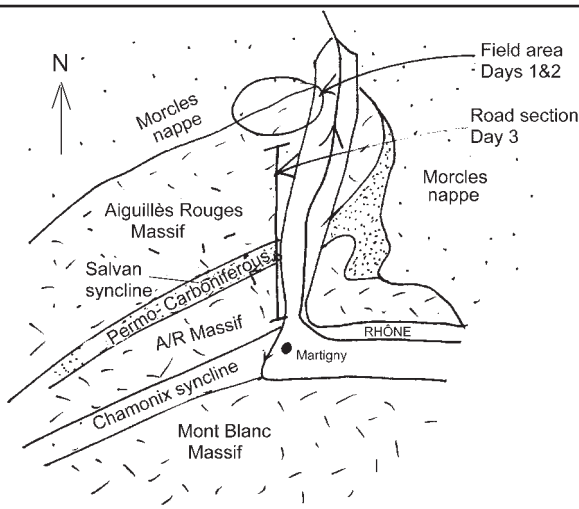

Figure 1. Geological sketch map of the Martigny area, showing locations for days 1 – 3. Days 1 and 2 were spent on the boundary between the Aiguillès Rouges Massif and the Morcles nappe. The road section on Day 3 traversed the Salvan and Chamonix synclines.

Philip Clark writes:

"There are really good memories of the three days based at Martigny dominated by the Morcles Nappe and the three based at Brig centred on the Zermatt-Saas ophiolite. Martigny was strenuous; the toil up from the campsite at Van d'en Haut, where the hardier members of the party were staying, to the dam of the Lac de Salanfe (from 1371m to 1925m) was alleviated by botany as much as geology: little yellow foxgloves and large yellow violets were as striking as the evidence for what had happened to the basement beneath the Nappe. The view from the Auberge de Salanfe is superb; the Tour Sallière across the lake and snow helping to pick out the sweeps and folds of the rocks above the unconformity. To the right the Morcles Nappe appears again in the Dents du Midi and Rochers de Gagnerie. The unconformity sweeps down to the lake from the Col de Jorat and to the left meets the skyline at the Col d'Emaney.

"Some of us simply had to struggle up its 2462m through the snow the second day. We were all rewarded by glimpses of a cloud-wrapped Mont Blanc to the south and I, because I was struggling up with my nose to the ground, found a dinosaur footprint in one of the few bits of Bunter Sandstone exposed in the track. Bill Fitches had earlier showed us some rather more splodgy footprints in the Bunter lower down, though the chief interest was the sub-Triassic unconformity beneath it, above the highly tormented crystalline basement.

"Returning home to Block 4 of S338, it was strange to find Bunter appearing as a good-quality reservoir in a Triassic hydrocarbon play. I prefer to think of the play of our dinosaurs on some lakeshore or flood plain! There were other good things around the lake: boulders of Jurassic limestone conglomerate strongly deformed by the Alpine orogeny; the tiny chocolate vanilla orchid; snowfalls off the Tour Sallière.

"The third day was tamer, roadside exposures of what the Variscan orogeny had done to the basement and distant views of the Dent de Morcles which gave its name to this lowest of the Alpine nappes."

Van d'En Haut to Lac de Salanfe *Day 1.*

- Pre-Alpine basement: schists and gneisses; medium grade regional metamorphism; polyphase deformation; Permian intrusion (Figure 1)
- Architecture of the Helvetic (External) Alps as seen from the Auberge de Salanfe: pre-Triassic basement; Triassic cover; Jurassic-Tertiary cover; Alpine (Tertiary) Morcles nappe
- Sedimentology, palaeontology of Mesozoic-Tertiary rocks
- Deformation of rocks in Morcles Nappe (Figure 2)

We campers were relieved to find on waking that Rob, the final member of our party, had turned up during the night! The group from the hotel arrived at the campsite at 8.30am in rather wet mist and, observing a snowline lower than the previous day, we checked with the warden to see if he had heard the weather forecast: "Comme ça", he said, which wasn't encouraging!

The route took us through pine trees and 600m up the back wall of the valley in the crystalline (gneissic) basement of the Aiguilles Rouge Massif. It climbed in a series of zigzags, supplemented by steel steps and ladders on the steep bits. Flowers and butterflies offered an opportunity for getting our breath back. Close to the top there was an exposure of a later, but still pre-Triassic, unde-

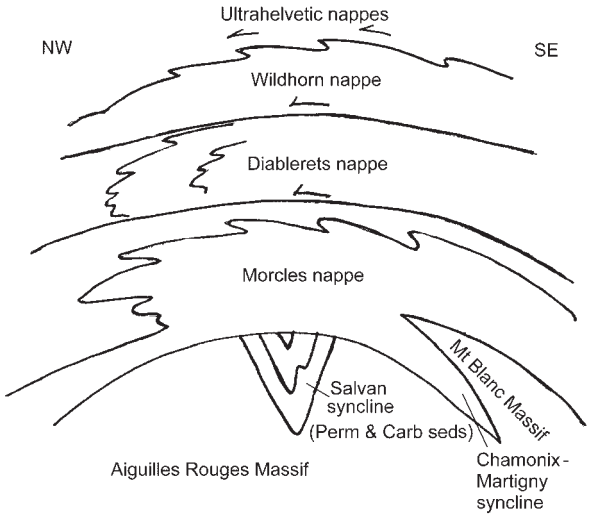

Figure 2 Alpine folding and thrusting in the Aiguilles Rouges – Mont Blanc area, showing the setting of the Salvan and Chamonix synclines, and the position of the Morcles nappe at the base of the nappe pile.

formed felsic intrusion: a porphyritic granite with phenocrysts of alkali feldspar, quartz and biotite (some chloritized) in a finer grained matrix. This is a dyke, which extends across the valley to crags on the northern side.

Arriving at the Auberge de Salanfe (1925m) we had a welcome lunch break, followed by Bill's explanation of the exceptionally interesting panorama that was spread out across the far side of the lake (to the west) through gaps in the mist and cloud (Figure 3).

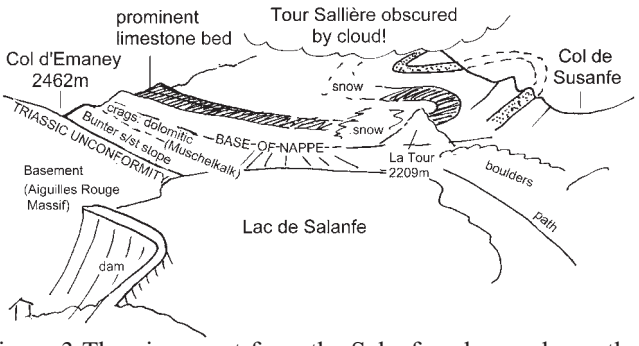

Figure 3 The view west from the Salanfe auberge shows the relationship between the Morcles nappe, the Triassic rocks and the basement. The boulder field we visited on Day 1 is on the right below the Col de Susanfe; the Day 2 area is on the left between the far end of the dam and the Col d'Emaney.

Auberge de Salanfe viewpoint

From our position on the northern flank of the Aiguilles Rouge Massif we were looking towards the younger 'cover' exposed in the face of the Tour Sallière. The cover is Mesozoic: Triassic, Jurassic and Cretaceous. Some of it is autochthonous (in place), but above is a series of nappes. Tour Sallière is formed from the lowest nappe in the pile, the Morcles Nappe (Figures 2 & 4) which is also the youngest nappe, having been thrust in beneath the other nappes in the pile. The lower limb of the nappe has moved perhaps 2 – 3km to the NW, whereas the upper limb has moved much further.

Tectonically important formations	Period
Flysch	Tertiary
Upper Cretaceous limestones	Cretaceous
Gault	
Urgonian limestone	
Drusbergschichten	
Kieselkalk	
Valanginian limestone	
Valanginian marls	Malm to Cretaceous
Malm limestone	Malm
Dogger sandstone and marls	Dogger
Lias slates	Lias
Triassic evaporites	Triassic
Muschelkalk	
Bunter sandstone	

Figure 4. Morcles Nappe (Jurassic – Tertiary) and Triassic stratigraphy.

The cover comprises a succession of shallow marine rocks, thousands of metres thick, deposited on a carbonate platform. The platform was extensive; there was probably very, very shallow water from here to Whitby on the Yorkshire coast. The rock types include shales, calcareous sandstones and a series of prominent, thick, white limestones. During the afternoon we walked along the northern shore of the lake to a boulder field below the Dents du Midi and the Col de Susanfe.

Boulders from the Morcles Nappe

We investigated these boulders and found that they were conglomerate, containing well rounded but poorly sorted (200mm downwards in size) clasts of limestone set in yellowish, calcareous cement, possibly dolomitic. Although the clasts appeared at first sight to be matrix supported some clasts were touching and, allowing for three dimensions, the rock is probably grain supported. The pebble beds can be traced for a long way across country so are probably marine rather than fluvial in origin. The limestone is relatively easily abraded to a round shape and, since the clasts are large, the environment would be fairly high energy. The thick-walled brachiopods, bivalves, corals and gastropods etc also indicate this. The most likely setting is shallow marine with tides and currents etc. The shelf was on a passive margin in an extensional environment where a series of syn-depositional normal faults allowed thickness changes to develop in the beds. Although we assume that the pebbles were originally approaching spherical shape, they are now sometimes very deformed; this can occur when plastic deformation distorts the crystal lattice. There also seemed to be some evidence of pressure solution along clast rims.

There are higher amounts of strain in the overturned beds in the base of the nappe and lower amounts of strain in the right-way-up beds on the upper limb. Overall, the clasts define a linear fabric parallel to the direction of movement of the nappe (towards the NNW).

An attentive audience of local cows, who got very friendly with one member of the party, appreciated Bill's explanation of strain variations (Figure 5)

Figure 5. Bill and the geological cow. In the foreground is a boulder of 'stretched' limestone from the Morcles Nappe. In the background is the Col d'Emaney, with the plane of the Triassic unconformity dipping down to the right just above Bill's head, and the nappe visible above the cow.

On the way back to Van d'En Haut we took the opportunity to investigate an alternative track – longer, but less steep. This was partially destroyed by a landslip a few years previously but it is now being regraded – the digger was in evidence whilst we were there - and provides 4WD access to the auberge.

Van d'En Haut to Col d'Emaney *Day 2.*

The programme for the day was to include:

- The unconformity between the Triassic succession and the metamorphic basement including Triassic stratigraphy and sedimentology, basal shallow water clastics (Bunter Sandstone), dinosaur footprints and Muschelkalk dolomite (Cargneule).
- Gold-arsenic mineralisation
- Pre-Alpine rock types; metamorphism; polyphase deformation
- Tertiary flysch turbidites, and Wildflysch olistostromes
- Alpine deformation fabrics

Half-past eight saw us hiking back up the trail to the Salanfe auberge again where we had a coffee break before heading off across the dam and up the track towards the Col d'Emaney, the notch in the skyline we had seen on the previous day.

The Unconformity and the Triassic succession

First stop was a streambed exposure of pinky-peach coloured rock. This is a well-cemented mixture of quartz and feldspar clasts with a little bit of pyrite causing some brown staining. The clasts are angular and poorly sorted – from 10mm down to sub-mm size – and we identified it as a sub-arkose. The bedding dips NW at about 40° and there are ripples on some bedding planes. This is the Bunter Sandstone at the base of the Triassic which lies above the basement and beneath the Morcles Nappe. Evaporites above the Bunter Sandstone and the Muschelkalk provided the lubrication for nappe emplacement.

We ate our lunch (enlivened by watching snowfalls on the Tour Sallière) and then left the track to walk up the unconformity surface towards a crag with a cave, seeing some Alpine Bells (*Soldanella*) on the way. Some of this surface was clinkery, probably remnants of rubble or regolith on the fossil land surface, over which the Bunter Sandstone was deposited. On the sandstone were symmetrical ripples, bifurcating occasionally, also worm burrows and what Bill believes (and I think he convinced us) are dinosaur footprints. This is certainly a likely location as it is a continuation of the famous dinosaur site at nearby Lac d'Emosson.

A gully to the east is floored by the unconformity; to the west there is an exposure of cross-bedded mixed shales and sands. These lie slightly above, or at the top of, the Bunter Sandstone which here is only 3 – 4m thick and beneath the Muschelkalk. They display various shallow water features: ripples and desiccation cracks as well as the crossbeds. The sandstone does not show much grain size variation and probably resulted from a flood of sediment, whereas the finer grained shale was deposited during quieter, lower-energy periods. The whole sequence is more mature and more quartz-rich than the Bunter Sandstone. The sandstone is finer-grained with more rounded grains and mud lenses, possibly rip-up clasts. The shales have ripples and desiccation cracks filled with sand from above. It seems likely that the whole sequence is lacustrine with seasonal changes in deposition and perhaps dinosaurs plodding along the edge. Tension gash arrays in the Bunter Sandstone show movement to the NW consistent with nappe movement and also with the general dip of the local Triassic beds and of the base of the Morcles nappe.

We moved on to look at an exposure of Muschelkalk and an old arsenic-gold mine – and also saw some black salamanders in a pool!

The knoll of Muschelkalk was a particularly windy exposure – but since most of this rock is halfway up a cliff face it was a good opportunity to see something a little more accessible! It is a carbonate breccia, much of which is dolomitic. Little bedding remains now, although it was probably bedded originally. It gives way upwards into sabkha deposits. This breccia is known in French as Cargneule. John Verncombe, when a Leeds undergraduate, suggested that it is a recent surface process and that the Muschelkalk is bedded below the surface. It has a complicated recent chemical weathering history: salt reactions have caused major volume changes which produce brecciation, with cavities caused by the volume changes and by weathering.

The gold mine

The mine produced arsenopyrite and gold which occurred in solid solution. We found yellowish, iridescent chalcopyrite and greyish-yellow rhombic arsenopyrite in a host rock of graphitic schist, banded marble and gneiss. Graphite in the schist reduces fluids and precipitates sulphides. Putting together a thesis for depositional environment we came up with a limestone platform with lagoons; this would give the marble (originally limestone) and the graphite schist (organic-rich shale). There is also a dark amphibolite which was originally mafic volcanic rock. Fluid circulation would have picked up sulphides, gold, iron, etc and redeposited them in veins. Apparently arsenic was mined in Victorian times

for ‘Cleansing Arsenic Balls’! More practically it is often a pathfinder for gold mineralization.

The dumps appear to have been reworked very recently. We found very little arsenopyrite which was abundant only 4-5 years ago. Bill Fitches’ guess is that the arsenopyrite has been taken out to extract the gold which is an exsolved phase in the sulphide.

By now some of us were beginning to feel a bit weary – we had climbed the equivalent of a ‘Munro’ and done a lot of geology on the way so, after sending the more energetic members of the group on up to the col (2462m) for a view of Mont Blanc, Bill showed the rest of us a loose block of limestone, from the nappe, on the way back to the footpath. Originally homogenous limestone it was now strongly deformed with a slaty cleavage. There was a lineation on the cleavage indicating flattening and shearing (extending the cleavage) and producing a linear fabric in the direction of nappe transport. Some of the coarser carbonate has been extended and boudinaged, and there are also cracks perpendicular to the direction of extension.

Some of the party went on from here to examine the Wildflysch olistostrome. This Tertiary unit comprises slabs of sheared, crystalline basement and yellow-brown Triassic dolomite in a grey limestone matrix. The basement ‘fragments’ are up to several hundred metres in length but most fragments are on a centimetre scale. The olistostrome is a submarine debris flow, perhaps generated off the fronts of incipient nappes. It is caught up in the Morcles nappe and is now upside down at the base of the nappe pile. The strongly flattened and elongated fragments (olistoliths) show the intense strain.

Finally we made our way back down to Van d’En Haut – with yet another stop at the auberge on the way!

Road section from Van d’En Bas to Martigny *Day 3.*

This road section (Figure 1 and Figure 2) enabled us to see:

- Carboniferous non-marine clastic sedimentary rocks in the Salvan Syncline, a pre-Alpine, late Variscan fold
- Alpine deformation of the Variscan basement rocks in the Triente Gorge
- A section through the Chamonix ‘syncline’ at Martigny (this is an Alpine ductile thrust zone between the internal Mont Blanc and external Aiguilles Rouges massifs); mylonitised basement and Mesozoic carbonates

(We had also hoped to include Alpine deformation of Liassic calcareous shales at Leytron but time beat us and we had to push on to get to Brig where we were staying for the next 3 nights.)

We packed up camp in the morning and were soon joined by the party from the hotel for the drive back down the winding road to Martigny 1000m below.

Van d’En Bas

Just between the Restaurant and the road tunnel there is an exposure of granite: randomly orientated, interlocking quartz, feldspar and biotite crystals with perhaps some muscovite. There were twinned megacrysts of alkali feldspar; some of the feldspars were altering to epidote and some of the micas to chlorite. Within the granite were dark ‘blobs’, mainly biotite, and we plumped for calling these autoliths since we could not prove whether they were xenoliths or autoliths from deeper magma. Some of the phenocrysts and also some of the enclaves have a preferred alignment, almost a gneissic texture in places. This could be a flow effect (Bill’s preference; see Figure 6) or rotation due to tectonic activity. This is part of a very large body - a post-main Hercynian intrusion similar to the Mont Blanc Massif or the ‘Vallorcine granite’ produced, along with other peralkaline intrusions (e.g. syenites) by melts evolved from portions of the subducting slab.

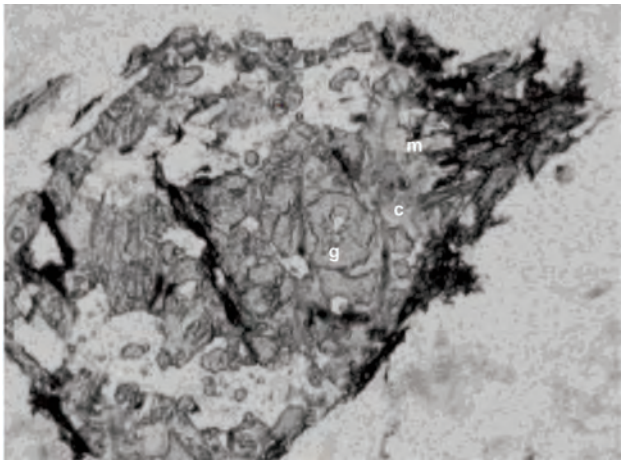

Figure 6. Photomicrograph of garnet-biotite (now chlorite)-muscovite-quartz-plagioclase schist/gneiss. Car park near hotel, 1st road tunnel on descent from Salanfe campsite towards Martigny. Main Variscan amphibolite facies assemblage with some Late Variscan retrogression (chlorite). m - muscovite; g - garnet; c - chlorite;plain polarized light (ppl).

Above Salvan

This is a deceptive and rather tricky locality (said Bill, and we agreed!). At the top end we thought we had a fairly fine-grained igneous rock with some muscovite and perhaps some alignment. However, walking downhill this becomes much coarser and it becomes clear that it is actually sedimentary – a fairly immature and poorly sorted (4mm → sub-mm) conglomerate or breccia with sub-rounded to angular clasts and some bedding. The mineralogy is confusingly similar to the granite we had just seen: quartz, white mica, feldspar and some darker minerals, but there were also clasts of gneissic basement material. We decided to classify the sandstone and conglomerate as litharenite or lithic arkose, probably produced by rapid erosion and a short time in transport. The environment would have been high energy, probably an alluvial fan where debris is deposited as the slope changes.

These are late Carboniferous-Permian sediments, deposited in inter-montane basins and now preserved in a series of late Variscan synclines (Figure 2). The synclines are eroded by the sub-Triassic unconformity which was followed by deposition, thus preserving the pockets of sediment.

The Dent du Morcles

We stopped just above Salvan to see some splendid examples of conglomerates and a stunning view of the Dent du Morcles, the type locality for the Morcles Nappe. Triassic rocks and autochthonous Mont Blanc Massif cover from the lower limb are exposed high up on the other side of the Rhône Valley. A ‘Z’ fold pair from the lower limb is exposed in the face of the Dent (Figure 7). This is a mirror image of the exposure we had seen on the previous two days in the face of the Tour Sallière.

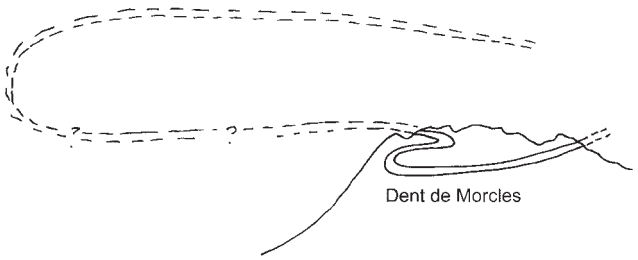

Figure 7. Location of Dent de Morcles in relation to Morcles Nappe. The major portion of the nappe has been removed by erosion, leaving this fold pair from the lower limb in the face of the Dent de Morcles.

The polymict conglomerate here contains clasts of quartz, gneiss, granite and rip-up clasts of very carbonaceous black shale. Fragments are rounded to angular and there is a clean contact between this and the sandstone above. There is a bit of tectonic fabric in the form of a preferred alignment (the associated shales have a phyllitic cleavage). The cleavage intersects the bedding and this shows the direction of fold plunge. This deformation is a late Variscan event (Permian).

After eating our sandwiches in Salvan village we continued down the hill.

Chamonix syncline at Martigny

We stopped by the garage at the foot of the hill to look at the Mesozoic rocks in the Tertiary 'syncline' which is sandwiched between two Helvetic Zone massifs, the Mont Blanc Massif to the south east and the Aiguilles Rouge Massif to the north west. This gap is a zone of weakness that has been exploited by weathering and erosion and consequently forms a topographic low. We started on the Aiguilles Rouge side (Figure 1) where folding in the late Cretaceous/Tertiary has produced compressional tectonics. A deep thrust/shear zone formed which carries the Mont Blanc massif over the Aiguilles Rouge massif and nips the cover rocks into the Chamonix syncline. Alpinization of the Aiguilles Rouge Massif overprinted Hercynian structures and we were able to see two fabrics in what were quartz-feldspar-mica basement gneisses. The relict Hercynian fabric is a very feeble dipping alignment whilst the Alpine is a steeper overprint (Figure 8a).

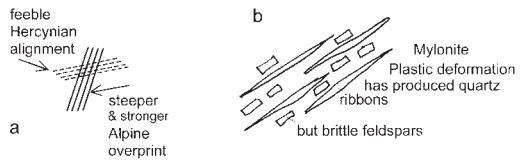

Figure 8. a) Alpine and Hercynian alignments. b) Quartz ribbons and brittle feldspars in mylonite.

Further along the road mylonite has been produced in a firmly alpinized zone. Bill described the difference between a cataclasite, a sort of microbreccia where rocks at a shallow level are ground up but with no grain alignment, and a mylonite that forms at deeper levels. At depth there is higher temperature and confining pressure. The strain rate is slower but fairly constant. During plastic deformation quartz ribbons are formed which are aligned along with micaceous minerals. Here we could see the quartz ribbons, but also brittle feldspars that had fractured, with pressure shadows developing at the ends (the temperature being insufficient for plastic deformation feldspar) (Figure 8b).

A series of *en echelon* quartz veins were produced where quartz filled gaps in boudinaged sections and was then foliated by later deformation. As we walked along we found changes in the mineralogy: as a result of mylonitization the feldspars have become micas or clay minerals and micas have also changed to other micas. Overall, the rocks were developing a schistose appearance. We were moving deeper into the zone and a steep linear fabric on the rock gave the sense of movement. Eventually arriving at the start of the built-up area, by a roadside cross dated 1891, we reached a zone of mylonitized limestone. This was the end of the transect, and time to move on to Brig, our next base. Philip Clark again:

"We travelled further up the Rhone valley to leave half the party at a very different, far more civilised, camp site, and the rest at a hotel in Brig. From there it is an easy journey up the valley of the Visp to Täsch, where cars must be left for Zermatt and the journey completed by train. The second day we indeed did this, and most of us joined the thronging hordes to ascend by the rack and pinion railway to Gornergrat and enjoy the sensational views of the Matterhorn and its attendant peaks and glaciers. As my nephew later commented, the Matterhorn 'is rather like the Hallelujah Chorus, no amount of poor quality reproduction can spoil it'.

"But on the first day from Brig we drove up from Täsch to Täschalp. In glorious weather we ascended this serene imposing mountain valley, the Wildhorn behind us, the ophiolite on our right and the vast moraine of the glacier ahead. Equally interesting were the glacial evidences, striations on the rocks, and the serpentinite, jadeite, and other witnesses that bits of an ocean floor had been obducted and carried high up over European continental crust. All this, a marmot and a chamois, and the flowers, dianthus, gentians and edelweiss continued to enchant us."

The Zermatt-Saas Fee ophiolite at Täschalp *Day 4.*

Having had a day off, we prepared ourselves for another of Bill's 'hard hiking days'. We had now moved from the Helvetic Zone to the Pennine (Internal) Zone and the object was to look at

- Alpine Pennine Zone stratigraphy above Täsch: alpinized Variscan basement, Triassic clastic and carbonate rocks, and Jurassic-Cretaceous cover (Schistes Lustrées/Bundnerschiefer)
- Zermatt-Saas Fee ophiolite: blueschist-eclogite facies ultrabasic rocks, metagabbros, metabasalts and pillow lavas and deep marine sedimentary rocks

The road to Täsch, just north of Zermatt, leaves the Rhône valley at Visp and from here the rocks of the Pennine Zone are gently inclined to the south. They are related to the Pennine nappes which, similarly to the Helvetic nappes, are transported from the south east towards the north west.

We followed the Vispertal south to Stahlden where the valley, and the road, forks, and took the western fork up the Mattertal past an impressive, fairly recent, landslip to the village of Täsch. This is the furthest cars are allowed up the valley, onward transport to Zermatt is by train. However, our route zigzagged up the valley side to the east and into the hanging valley, the Täschalp, 800m above with the hamlet of Ottovan at its entrance. With more time (and energy) to spare we could have detoured up the path to Täschhutte where it is possible to see basement and cover sitting

on the Pennine Zone. However, we had 5km to walk up the valley to a heap of moraine at the top end. The walk was enlivened by the wild flowers, some of the best we'd seen: a true 'Alpine meadow', and we finally reached the foot of the moraine.

Foot of the moraine

We ate our lunch here and then had a look around to see what we could see and soon amassed a collection of varied rocks. I was particularly taken with an actinolite-mica schist and a piece of meta-basalt containing lawsonite porphyroblasts, that were retrogressing to zoisite, and phengite. The fragments in the moraine are derived from the ophiolite, which has a base of depleted mantle peridotite. The mineralogy of this ultrabasic rock is olivine, enstatite (orthopyroxene), augite (clinopyroxene), chromite and magnetite. Partial melting produced gabbroic magmas in magma chambers along a spreading axis. These have crystallized to produce layered gabbros and cumulates. The magma chambers fed dyke complexes that in turn fed basalt pillow lavas. Deep-water sediments accumulated on top of this; calcareous or siliceous oozes rich in manganese, which formed umbers. Eventually the whole lot was 'shoved down a subduction zone' deep enough and fast enough to produce low temperature, high-pressure metamorphism.

Metamorphic reactions

Dealing with the simplest first, the mantle peridotite, perhaps a dunite, was composed of olivine and orthopyroxene. This has now been altered to soft serpentinite, blue- or green-grey, nondescript, fine-grained and rather schistose in appearance, ± talc formed from alteration of Mg-rich olivine and orthopyroxene. The green colouration probably comes from chromite. There are also spinels, magnetite and chromite, relics of the original ultramafic rock that survived alteration.

The gabbro was originally composed of plagioclase and clinopyroxene, ±olivine, ± orthopyroxene. It is now coarse grained with white and dark minerals and a foliated appearance.

The plagioclase has gone from the calcic (An) end of the series to the sodic (Ab) end of the series during metamorphism. There is some lawsonite, which has a formula equivalent to anorthite $+H_2O$; lawsonite takes the place of the anorthite component of plagioclase. Albite, plus quartz, has formed jadeite or jadeitic pyroxene. Dark augite has been partially replaced by jadeitic pyroxene, the amount of replacement related to the amount of pressure. The jadeitic pyroxene, a distinctive 'apple' green, is an Na-rich pyroxene; the amount of substitution of Na, the jadeite component, increases with pressure.

The basalts (dykes and lavas) have ended up with some garnets and white, <> shaped lawsonite derived by high-pressure metamorphism of the Ca plagioclase. Lawsonite is an extremely good high-pressure indicator. However, this has now been replaced, during lower P, higher T retrogression, by zoisite (a hydrous Ca-Al silicate and an iron-free member of the epidote family). The blue, almost purplish colour of the basalt is due to abundant glaucophane, for these are blueschists (see Figure 9). This is an Na-rich amphibole produced by metamorphism of Na-rich igneous rocks. It occurs as elongated prism shaped <> crystals with 120° cleavage. There are often also little dark green needles of actinolite (another amphibole, Fe-rich, that forms a solid solution series with Mg-rich tremolite) and a white mica, phengite (a relatively

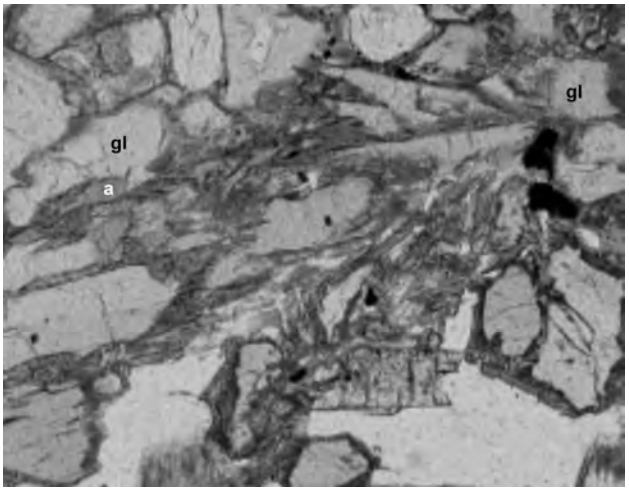

Figure 9. Photomicrograph of blueschist facies metabasalt from Täsch ophiolite. Glaucophane and actinolite are both amphiboles. Here the glaucophane records the High P, Low T blueschist-eclogite descent of the ophiolite, whilst the actinolite records the beginnings of Low P, Low T greenschist retrogression during ascent and obduction. a - actinolite; gl - blue glaucophane with rims; ppl.

Mg-rich form of muscovite). The general Na-richness of these minerals is promoted by the seawater reactions that take place; we also found a dark, Mg-rich mica, phlogopite.

The moraine and the ophiolite

Rob Tripp takes up the story at this point:

> "After lunch there was a lot of gasping and huffing and puffing as we made our way up stable, well-bedded-down moraine, with moss and lichen growing on the boulders. Unfortunately, the path was not designed to go to the ophiolite, but somewhere else up the mountain! However, it did help the group to get closer. We ended up on an unstable knife-edge ridge where chamois had been leaping around a few minutes previously. The glacier stream on the far side of this had cut into the moraine, eroding it and resulting in a steep, collapsing slope between us and the ophiolite, which was 'somewhere over there' under the glacier.
>
> "One agile member of the group found a way across, but discretion ruled and the rest felt that any attempt to continue further would result at best in landing at the bottom in undignified heaps. We were at the right height, but too far over and could see our objective away across the valley on bare rock at the toe of the glacier. We realised we had come the wrong way and should have followed the path that led up the north side of the moraine from the lunch spot."

(The *in-situ* ophiolite is exposed in the rock platform between the moraine and the glacier. To reach the platform, stay on the nearly horizontal path rather than try the steep path, which may seem to offer a short cut – but does not! WRF)

> "Returning down the natural fall line of the stream we came across three very large blocks (minibus sized) that saved the day as they were made up of pillow lavas. This enabled us to see that these had been squashed and appeared to show some zonation, for example there were areas relatively free of lawsonite. These lawsonite-poor outer shells may be original chilled margins?"

A day off *Day 5.*

Many of the group used this opportunity to return to Täsch where they took the train to Zermatt and then on the rack railway up to the Gornergrat for some splendid views of the Matterhorn and the snowfields and glaciers surrounding it. A number opted to walk down.

Martin and Jenny Elsworth took an 'alternative day off' into the Bernese Oberland to the north:

"The previous day we had driven through the valley bottom village of Täsch on our way to explore the Zermatt-Saas Fee ophiolite above Täschalp. Täsch is the Park and Ride place for hundreds of car and coach passengers wanting to make their way into Zermatt (a car free zone) and, perhaps, take the rack and pinion railway to Gornergrat for a close up view of the 4,478m Matterhorn, the highest peak in the Pennine Alps. Many of the party thought this would be a good way to spend the following 'free' day. On our way down from Täschalp we got a splendid sighting of this giant peak from a thoughtfully placed platform for viewing and photography.

"We really needed a rest day and time to buy and write post cards. So, early next day we mutually vetoed the plan to return 'to do the Matterhorn' and set off into Brig to find some cards. Amongst the post-cards on offer around town were views of the Aletsch glacier but we could not buy them, as we had not been there! We had no idea of its location but guessed that it must be somewhere close. But we did buy some post-cards showing the aftermath of the devastating flash floods in 1993 when car sized boulders crashed through the main street after the bridge over the Saltina River obstructed their passage. There is now a new bridge over the Saltina, which will automatically lift up out of the way if the river level rises too far. We toured the town and admired the three towers of the Stockalper castle, with their beautiful bronze coloured onion shaped domes, which is now the town's administrative centre.

"Having 'done' the town we decided to head off across the Rhône via Naters to find somewhere for lunch without a hand-made butty in sight anywhere. Zigzagging our way on we came to Blatten, a village with a ski-lift, which took us high up the valley side to Belalp. There we found an inn and asked for a menu – there was only one dish – homemade burger and chips! Washed down with a beer, in bright sunshine, on an uncrowded balcony with a magnificent view across to the Simplon Pass and a small scale Brig in the valley bottom, it was delicious.

"A gentle walk was needed after lunch so we set off in the direction most other people seemed to be heading and found ourselves following a pleasant level path through wonderful floriferous alpine meadows.

"At the end of the pathway, having passed by some contorted crystalline basement, we came to a view point and there, out of sight until the very last moment, was the longest glacier in Europe. Arising in the southern vicinity of the Jungfrau in the Bernese Oberland, the Aletschgletscher results from the merger of three major glaciers, its icy white surface etched with distinctive dark, tram-line like, medial moraines and its snout melts into the Massaschlucht, a feeder stream for the Rhône. (A colleague from work told me that he had walked along this glacier and that the moraines were rich in large pieces of galena).

"The day had been gloriously sunny and the views of the snowy mountain peaks all around us were awesome but we finished with yet another surprise: when we turned to walk back we saw another view of the Matterhorn – about the size of a thimble on the far horizon! We were delighted with the unexpected outcome of our refreshing day off from serious geology. On our return to England we reviewed our knowledge of the physics of glaciers and looked up pictures and details of the Aletschgletscher on the Internet: <http://mikeaz.free.fr/marjelen/marjelen.htm>"

To Locarno, via the Simplon Pass and northern Italy *Day 6.*

Refreshed by our day off, we met up at the campsite the following morning to drive to Locarno. On the way we were to see

- Liassic marls and Triassic evaporites of the Gotthard massif, deformed at the Pennine front
- A section through the Pennine Zone, over the Simplon Pass
- Insubric line mylonites at Villadossola (Italy)
- Ivrea Zone granulite facies ultrabasic rocks at Finero (Italy)

Napoleon Bridge (Napoleonbrücke)

This first locality was a short way south of the town of Brig and accessed beneath a flyover of the main Simplon Pass road. To reach it we walked along the bank of an old leat above the Saltina valley. This is an important locality where the Aar massif and the Gotthard massif are separated by the Tavetschezwischengebirge syncline (Figure 10).

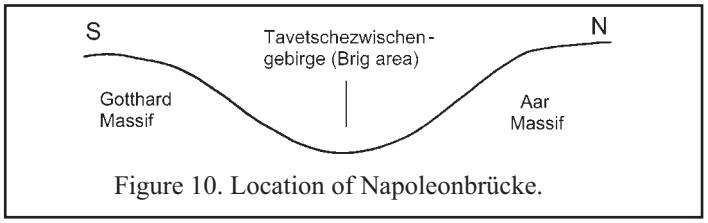

Figure 10. Location of Napoleonbrücke.

The basement rocks we saw at Martigny have dived beneath the Helvetic nappes in the Wildstrubel depression and reappeared at Brig. At this locality there is a glimpse of the junction between the Helvetic and the Pennine Zones; we are actually on the Gotthard Massif which has Triassic and then Liassic cover. The original marls are now very low-grade metamorphic rocks. The St Bernard Nappe (the lowest of the Pennine nappes) approaching from the south with its burden of cover, was brought into contact with the Gotthard Massif and its cover.

Exposure 1

A phyllite with a sub-vertically inclined cleavage. There are some quartz veins conformable with the cleavage. This was originally a carbonaceous mudrock. It is iron rich (pyrite) and formed in anoxic conditions. The bedding is difficult to find as it is very even textured. It probably formed in low energy conditions in a lagoon on the Liassic carbonate platform. It was metamorphosed to mid greenschist facies (chloritoid, and also a bit of chlorite); the chloritoid is black, shiny and looks a bit like biotite, but is prismatic rather than flaky. There is no biotite, but this is probably because of the rock chemistry.

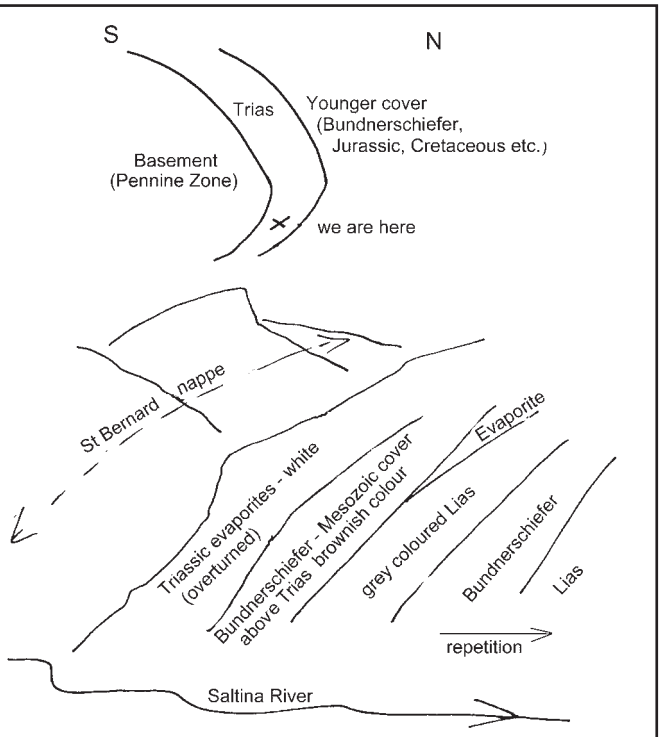

Figure 11. Exposure across valley at Napoleonbrücke.

Exposure 2

The phyllite shows tight and isoclinal folds with a crenulation cleavage deforming the penetrative cleavage seen at the last exposure.

Exposure 3

Ilmenite is present here; it is a dark brown, prismatic mineral with crystals 1 – 2mm long.

Exposure 4

A white cliff of evaporite: gypsum and anhydrite; there was originally halite in the succession but under elevated pressure and temperature this is very plastic and has now been dissolved away. The gypsum is very soft (2 on Moh's scale), $CaSO_4.2H_2O$. The anhydrite, $CaSO_4$, is harder (7). One is hydrated, the other not: the dehydration reaction, $CaSO_4.2H_2O \leftrightarrow CaSO_4 + 2H_2O$, occurs at >105°C. Burial elevates the temperature and converts the original gypsum to anhydrite and water. The water lowers the rock strength and provides a high fluid pressure layer on which the nappe can glide (analogous to the high pressure air cushion which makes a hovercraft highly mobile), making the rocks highly mobile and assisting nappe emplacement as at Salanfe. The ductile halite would also have aided lubrication and mobility. These are the Triassic evaporites that sit on the basement below the St Bernard Nappe and are probably shallow marine or lacustrine in a situation where saline water collected and there was a high evaporation rate. It was probably a dry, or a seasonally dry, climate with drainage away from the basin, possibly a sabkha setting.

We had moved into the Pennine Zone after walking through the Liassic cover of the St Gotthard Massif. To the south there is crystalline basement with Triassic cover; above that is Mesozoic and Tertiary cover: Bundnerschiefer, Jurassic and Cretaceous rocks.

From the viewpoint we could see the exposed thrust zone between the Pennine nappe Bundnerschiefer and the Liassic cover of the St Gotthard Massif. Slices of both rock types are repeated along the section and movement has been facilitated by the Triassic evaporites (Figure 11)

After an early stop for lunch at the top of the Simplon Pass Jan and I went ahead to find a campsite and make arrangements with the hotel in Locarno. Bill led the group on towards Italy and stopped at an abandoned quarry area near Villadossola; he has contributed this account of the rest of the day.

"Insubric Line

Owing to a massive invasion by buddleias, this site is no longer accessible without a trained group of machete-wielders!

"At the workshed one can still see outcrops of Hercynian gneisses, tight to isoclinally folded on steep axial planes by Alpine overprint. There are cut stones and slates of the fully alpinized Hercynian rocks: these are grey-green mylonites with streaked out quartz (ribbons) and relict brittle-deformed feldspars in a matrix of chlorite and epidote (both green).

"Finero Church – Ivrea zone

From Mallasco we took the squiggly little road to Finero village and parked by the monument to World War II patriots. Within 100m of Finero church there are three features:

1) Granulite facies ultrabasic rocks: these have a deceptive appearance because they have a yellow-brown weathering crust and they are fast becoming engulfed in vegetation. They are layered on a 10 – 15mm scale and contain olivine (yellow-brown weathering, pale green when fresh), orthopyroxene (dark brown weathering) and spinel (probably magnetite or chromite) which occurs as tiny black octohedra that are concentrated in particular layers and help to pick out the igneous layering (see Figure 12).

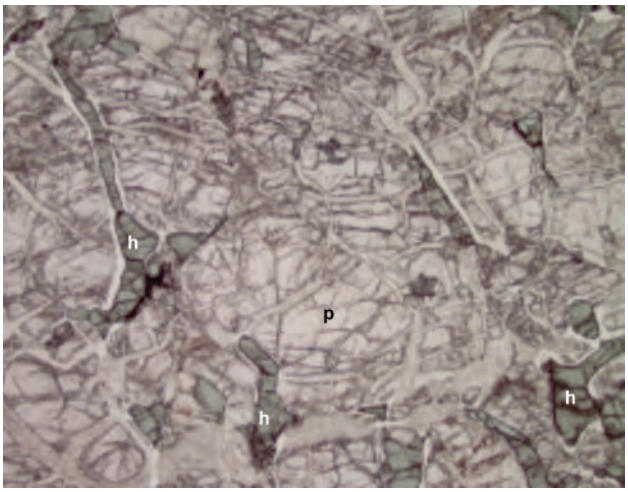

Figure 12. Photomicrograph of olivine-clinopyroxene-orthopyroxene-hercynite (green spinel) ultrabasic rock from Finero Church, Ivrea Zone. Granulite facies assemblage. Very deep crustal metamorphism. Ol and opx partly serpentinized. h - hercynite; p - pyroxene; o - olivine; ppl.

2) Granulite facies basic rocks (metagabbro) are exposed in outcrops overlooking the valley side. They are coarse grained and contain black clinopyroxene, brownish orthopyroxene and white plagioclase, with concentrations of garnet. They are layered on a 50 – 500mm scale.

The layering of the ultrabasic and basic rocks (1 and 2) is probably of igneous origin (cf Skaergaard, Great Dyke, etc.) It was originally an ultra basic – basic complex, some say an ophiolite, others an intrusion, others very deep crust. This would have been pre-Alpine crust, Variscan or older, thrust up by Alpine events. It must have come up quickly in order to preserve granulite facies assemblages without retrogression (cf the Zermatt-Saas Fee ophiolite).

3) At the top of the slope immediately behind the church is a meta-gabbro containing sapphirine. This is inky blue but very difficult to identify with certainty. The sapphirine and quartz assemblage implies >40km depth of burial.

"We made a quick stop at St Ré – a tourist stop for locals, with lots of goodies in little shops: hams, saucisson, grappa and other indigenous spirits, some containing leaves, grass, etc, to make them look palatable and healthy. There were also ice cream shops ('just one cornetto'!) to fortify us for the awful winding drive down the Centovalli to Locarno."

Pennine nappes above Fusio in the Maggia valley *Day 7.*

The field area for the next two days lay well up into the Alps north of Locarno. This is the Pennine Zone again, which we had crossed on the previous day. During this first day (a short day Bill promised) we would be looking at typical Pennine Zone geology:

- Pre-Triassic metasedimentary rocks involved in several Variscan events (amphibolite facies), then Alpine tectonic-metamorphic events (also amphibolite facies)
- Permian plutonic rocks deformed and metamorphosed only in Alpine events
- Triassic sandstones and dolomites deformed and metamorphosed in Alpine events (e.g. tremolite-actinolite)
- Jurassic (Bundnerschiefer) marls and mudrocks deformed and metamorphosed in Alpine events (e.g. garnet, staurolite, kyanite)

After a drive of about 30km up the Maggia Valley we turned up into the Val Lavizzara at Bignasco. At Peccia a set of zigzags lifted us up into a hanging valley and above Fusio we entered the Val Sambuco with a 3km drive high above a rather sinister reservoir and then on to park by the lower of the two small Laghetti lakes. Isa (who had driven down overnight from Frankfurt) takes up the story:

"We drove what seemed to be ages up this mountain and stopped for a natural pause and then carried onto Fusio and above. Hairpin bends and single-track roads were our lot and although I am used to them I felt a little car-sick (probably because I was sitting in the back). The top of the mountain was beautiful. I was suddenly aware that the temperature was no longer the warm temperature of the valley below but one that required jumpers and wind-breakers. Kitted up we started our tour: roadside cuttings up the mountain.

"We had a close look at gneisses formed from the igneous tonalite, including some country rock xenoliths/inclusions. There were some aplite and tonalite intrusions in some of the gneisses and further up the road we also found some folded aplites and folded biotite crystals. There were also rootless folds from the pre-Permian basin and some augen gneisses, a very curious lithology displaying some white feldspar spots in a darker-grey matrix. The spots looking as eyes in a rock (hence the augen = eyes in German). A series of alternate intrusion and screen folding caught my eye as I was surprised by the intricate folding and variation of structure within one outcrop. There were 1st, 2nd and 3rd deformation structures (e.g. hook folds) in this rock."

The metamorphic rocks at the start of the section showed a strong alignment caused by strung out clumps of minerals rather than individual aligned minerals (Figure 13a).

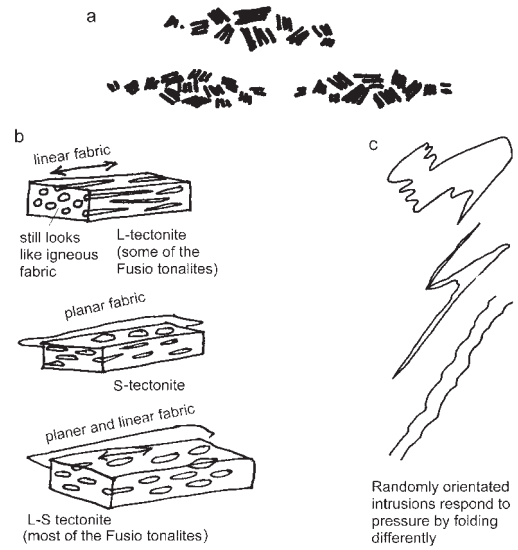

Figure 13. a) Alignment formed by strung out clumps of minerals. b) L-tectonite and S-tectonite fabrics (WRF). c) Responses to deformation in differently orientated veins.

We found quartz, alkali and plagioclase feldspar, biotite (some appearing gold because of weathering), blocky black amphiboles (possibly hornblende) and small amounts of muscovite and epidote. There were dark enclaves, originally xenoliths and composed of biotite and a little amphibole. This rock is a biotite-amphibole gneiss, originally a tonalite although some darker areas are nearer a diorite composition. (Tonalite = quartz > 20%, plagioclase >> alkali feldspar + biotite + amphibole. Diorite = quartz > 10%, plagioclase >> alkali feldspar + amphibole (pyroxene originally). Tonalite is described as 'quartz diorite' in some literature.) This would have been a coarsely crystalline granitoid rock with xenoliths (autoliths?) from early phase crystallization. It is a similar age (Permian) to the granite we saw at Van d'En Bas on Day 3, and results from late, post-Variscan but pre-Triassic (pre-Alpine) tectonism. The texture is similar to the original igneous fabric, when viewed down the axis of this linear tectonite (or L-tectonite), as opposed to a schistose or S-tectonite, which has a planar fabric (Figure 13b).

After lunch we carried on up the hill, noting some minor intrusions of darker micro-tonalite and also variations in the strain between an L-and an S-fabric and some garnet.

We broke off to look across the upper Laghetti lake for a view of 'tomorrow'. Probably a good thing we did since the following day was so misty that views were rare. Other features up this stretch of road included aplite veins, folded by back thrusting during the Alpine orogeny and deforming the earlier fabric. The

aplite is very light coloured, fine grained granitic material, mainly quartz and feldspar, with very little biotite but high silica content, perhaps 75%. In other places these veins are boudinaged.

Just past the path we would follow on the next day was a section with a different appearance: grey porphyroblasts and blobs of country rock with stripes of intruded material. A little further up dark country rocks were light spotted and included some very highly folded lighter patches of fine grained Permian tonalites, perhaps from the intrusion but more likely earlier as they showed a very complex tectonic history. The random orientation of these intrusions showed different responses to deformation (Figure 13c).

These are in the marginal zone of an intrusion where sheets and veins are being sent out into the surrounding psammitic biotite schists and gneisses. Originally this would have been a tonalite with screens of country rock; now Alpine structures have been imposed on Hercynian structures. We saw interference folds 'co-axial refolds' and also a shear zone. Folds in one exposure showed how folds with different wavelengths can be produced in different layers. Biot produced an impressive simplified equation for this, which showed how the wavelength is controlled by:

1) the thickness of the competent layer

2) the competency contrast between the competent and incompetent layers

Across the lake we had another view of tomorrow's locality. We could see lens-shaped pods of rock and relatively undeformed rock in the tonalite crags above the lake surrounded by braided shear zones. These show up well because the shear zones are schistose and more prone to weathering.

Isa again:

> "After a fair walk we ended up at the top of the mountain in the Pennine zone near a dam and here the outcrop was indeed very different: yellowy white and grey flat strata inclined at about 50°. These rocks were part of a deformed isoclinal fold and the yellow stone was dolomite marble. There was also some very white calcite marble."

This zone is in contrast, tectonically and metamorphically, to the Helvetic dolomite at Salanfe. Here all the rocks have been caught up in Alpine deformation and metamorphism. There is recrystallization to tremolite (which was also seen in the Zermatt-Saas Fee ophiolite).

Tremolite is an Mg-silicate that has derived its magnesium from the dolomite ($CaMgCO_3$). The 'silicate' bit comes from quartz ±silicate from clay minerals in the original impure dolomitic sediment. (In the ophiolite tremolite Mg came from the Mg-rich olivine and pyroxene in the ultrabasics). We also found the yellowish Mg-mica phlogopite. Isa continues:

> "We then moved onto another outcrop a little further downhill (over side of mountain), and found some brown-black garnet crystals in graphitic-mica-calc-schists, including other minerals as porphyroblasts, and kyanite. These were part of an outcrop originating from Jurassic (Bundnerschiefer) argillaceous sedimentary beds (marls and mudrocks) interbedded with carbonate rocks from deep water. There are foraminifera (*Globigerina*) in the deep-water muds."

This is Pennine Zone cover younger than the Trias, formed in deep water off a carbonate shelf. It has been heavily metamorphosed:

1) Muscovite, biotite, porphyroblasts of garnet and staurolite, quartz and (?) plagioclase. There is a lot of graphite and also some pyrite. This was originally organic-rich black shale.

2) The calcareous rock indicates that the sequence must have been formed above the carbonate compensation depth, no more than around 1000m, but still off shelf.

We found kyanite, and muscovite going to kyanite, in a quartz vein. This is a high-pressure mineral in a low-pressure vein and may have been produced from muscovite at the vein margins during Alpine metamorphism. The original pegmatite/vein was zoned, with muscovite books in the marginal zone (a very common arrangement in veins and pegmatites), then muscovite ↔ kyanite + quartz + K feldspar during Alpine high P and T metamorphism.

The staurolite and garnet are black in colour, due to abundant graphite inclusions (sourced from organic matter). The original schistosity was produced during nappe formation. This was followed by metamorphism caused by the thermal blanket of the nappe stack (Figure 14).

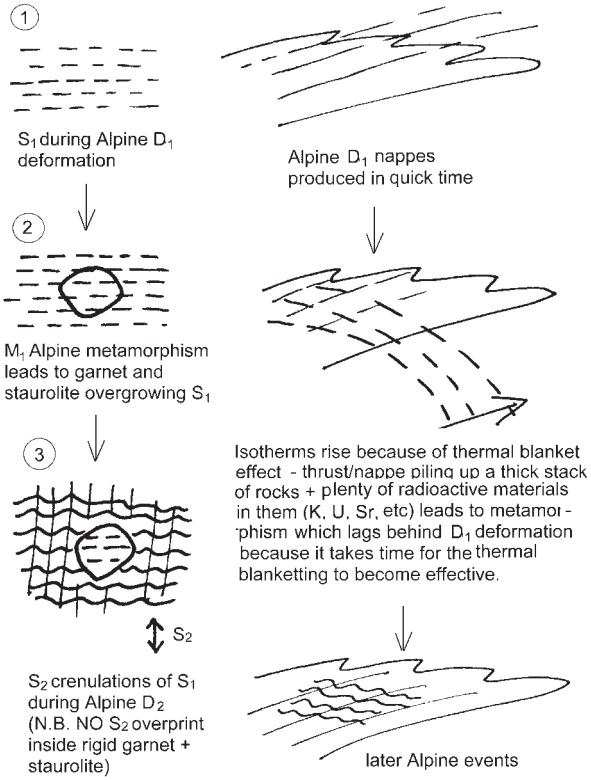
1
S_1 during Alpine D_1 deformation
Alpine D_1 nappes produced in quick time
2
M_1 Alpine metamorphism leads to garnet and staurolite overgrowing S_1
3
Isotherms rise because of thermal blanket effect - thrust/nappe piling up a thick stack of rocks + plenty of radioactive materials in them (K, U, Sr, etc) leads to metamor-phism which lags behind D_1 deformation because it takes time for the thermal blanketting to become effective.
S_2
S_2 crenulations of S_1 during Alpine D_2 (N.B. NO S_2 overprint inside rigid garnet + staurolite)
later Alpine events

Figure 14. Deformation and metamorphism relationships at Laghetti. (WRF)

Isa concludes:

> "The rest of the day was spent walking back up and then down the mountain side again and then back to the hotel for shower and dinner."

At this point Jan and I, with the luxury of the camper van, decided it was pointless to return to Locarno and stayed put on the mountainside for the night. The mist soon descended and there was an eerie silence broken by the occasional interruption; a string of motorcyclists rode past on their way to the 'top' and then

back down again. Another car parked a couple of hundred yards-away for the night (courting couple?) and a herd of goats, bells jangling, wended their way up the mountain at dusk and then back down again at dawn.

The Laghetti shear zones above Fusio *Day 8.*

The following morning the party turned up as planned, but unfortunately the weather did not look at all promising.

- The plan for the day was to spend the morning on a spur above the Laghetti lakes, investigating the shear zones. These are Alpine ductile shear zones in late Variscan, pre-Alpine Permian granitoid plutons
- In the afternoon we were to see a profile through the Pennine Nappe pile; a downward facing fold in the Passo di Naret area higher up at the top end of the valley

In the event the weather turned out so bad that it took us all day to cover the first locality; even if we had had time the mist was so thick that the second locality would have been a complete non-starter. Isa sets the scene:

> "The next day we went up another part of the same mountain but this time to look at the Laghetti Shear Zones. After a very steep climb (crawl!) up the slope we arrived near the top when rain started. So getting wet we carried on climbing to a ductile shear zone area (Alpine shearing of late Variscan intrusions) of great interest. Here were coarse-grained granites (pre-Alpine Permian granitoid plutons) with country rock xenoliths as well as lamprophyre dykes, which show evidence of deformation by the Alpine events but were intruded during the Variscan Orogeny. The effect of the shearing was noted when looking at the fairly round structures of the xenoliths deformed into elongated shapes and veins normally fairly straight being folded into buckled folds. The granite crystals took a rather aligned structure, resembling gneisses but the crystals were only re-shaped by the shear rather than forming distinct lineations in the gneisses. Some dykes were also present and a relative age was established for the rocks in this outcrop."

The Laghetti area is globally famous: the ductile shear zones here were first recognised by John Ramsay and R H Graham whodealt specifically with the Laghetti area as one of their examples of a 'ductile shear zone'. The zones were formed at deep levels in the crust and are similar to those seen in places in the Outer Hebrides. The setting is similar to Salanfe: Permian intrusions were uplifted and eroded, becoming planed off as a base for the Triassic unconformity and deposition of the Bundnerschiefer and the Jurassic and Cretaceous. At the start of the Alpine Orogeny the igneous rocks were at a depth of around 15km and temperatures of 500 - 550°C. This links in with the presence of garnet, kyanite and staurolite that we saw in this area the day before. Bill explained that the controls on deformation here are: temperature, confining pressure, rock type, strain rate and water.

The rocks here have been sheared by ductile deformation instead of brittle faulting/fracturing. Ductile deformation takes place at deeper levels in the crust and is favoured by:

- elevated temperatures (> *c.* 300°C, the onset of greenschist facies conditions)
- slow strain rates (high strain rates favour brittle faulting)
- high confining pressure (confining pressure increases with depth in the crust)
- high fluid pressures ('wet' rocks deform more easily than 'dry' ones)

We looked at the fabric closely and found that quartz phenocrysts, originally equant, had become streaked out and elongated in the shear zones. The quartz had deformed by ductile deformation, but the feldspars still behave in brittle fashion; feldspar cannot deform by ductile deformation until *c.* 550°C. There were some amazing examples: the tonalite with xenoliths or, more probably, autoliths is mainly undeformed. However, in the shear zones the autoliths are rotated and stretched achieving something in the region of a 20:1 ratio. The matrix becomes foliated. Perhaps most impressive is the region along the edge of the shear zones where the fabric changes (Figure 15a).

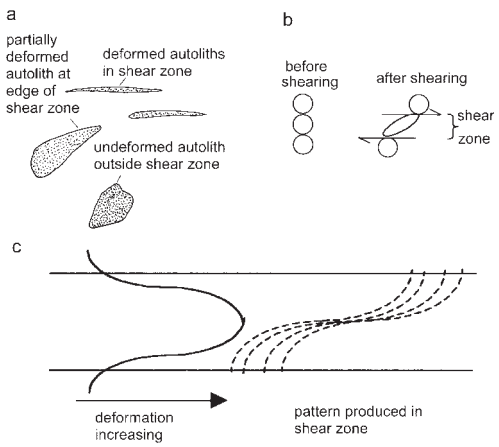

Figure 15. a) Deformed, partially deformed and undeformed autoliths at the edge of a shear zone in tonalite. b) Material outside a shear zone is displaced without shearing. Material within the shear zone is distorted. c) Deformation is greatest in the centre of a shear zone, producing sigmoidal patterns.

Isa comments:

> "All this geology was paused for our lunch at which point I decided to sit down, as I was so wet it surely would never get me any wetter! It didn't! Rain dripped from my hair, arms, rucksack, trousers ... everywhere and everything was wet! My passport was a very sore sight when I eventually found it at the bottom of the little pocket I have in my geology jacket, which I wore under a waterproof (really???) jacket…"

After lunch we wandered around the hilltop looking for more examples of simple shear, interspersed with mini-tutorials by Bill. He explained how there can be displacement without distortion outside the shear zone, but distortion within the zone where planar fabrics develop, eventually becoming parallel to the edges of the shear zone (Figure 15b).

Sigmoidal deformation is feeble at the edge, but increases towards the centre of the zone and this can be demonstrated graphically (Figure 15c).

Pegmatite veins crossing the tonalite are normally straight but where they cross a shear zone they are deformed and may be boudinaged or buckled, depending on their orientation (Figure

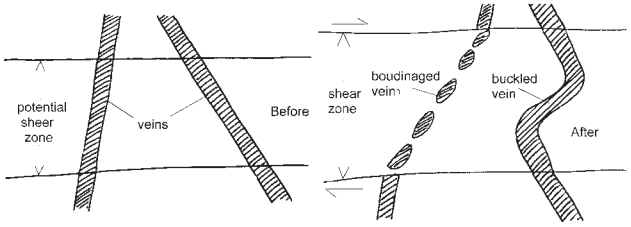

Figure 16. Veins crossing shear zones at different angles may be stretched, sometimes producing boudinage, or they may be buckled into folds.

16). A vein nearly parallel to the long axis of the strain ellipse will be boudinaged whereas veins nearly parallel to the short axis of the ellipse will be folded.

One example of a buckle fold showed how fabric in the tonalite was mainly axial planar, but fanned outwards in the inner arc and inwards in the outer arc (Figure 17).

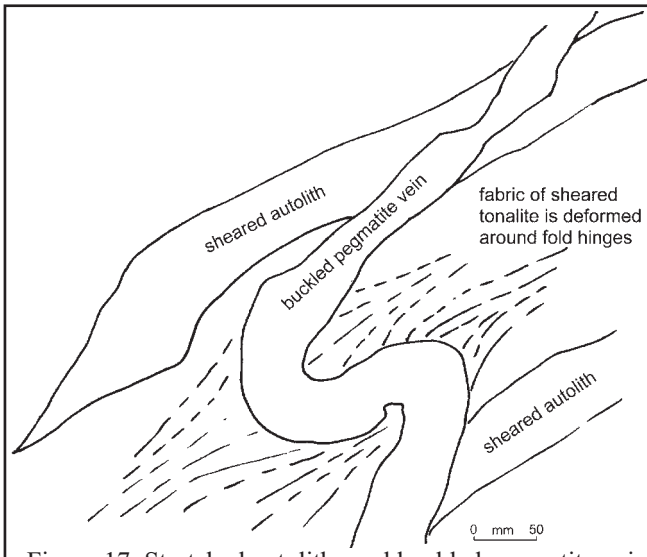

Figure 17. Stretched autoliths and buckled pegmatite vein.

Isa continues:

"After this rather dull day (weather wise!) we descended back down in the mist and did our first impersonation of 'gorillas in the mist'! However, by then we were cold and very wet and the prospect of a cup of tea or coffee in a little local tea house in the very lovely village of Fusio was very welcome. We all went there and had a lovely tea/coffee and at that point it was time for me to take my leave of our hosts and say farewell to the new friends I had made."

Acquacalda *Day 9.*

The following day there was no real improvement in the weather as we drove from Locarno to Acquacalda near the summit of the Lukmanier Pass where we were to spend the night. We arrived at Acquacalda around lunchtime in mist and pouring rain and it became clear that there would be little geology done that day. The inn here is run as an Ecological Centre for Man and Nature (Centro Uomonatur) and the director, Luigi Ferrari, whom Bill had known from previous visits, gave us a talk about the aims of the centre. They organise holidays and there is a 'Naturetum', a park for contemplation of Alpine Nature. Following that Bill gave us a useful summary of what we had seen so far and eventually we donned waterproofs and, braving the persistent downpour, headed a few kilometres back down the valley to have a look at the alpine deformed basement schists by the river bridge and also up a track above the hamlet of Piano where there is kyanite, garnet, staurolite, actinolite and anthophyllite. Regretfully we didn't reach the anthophyllite locality near the hamlet of Fiodelero (abandoned but re-emerging as a weekend chalet site) where there are spectacular rocks (when in sunshine!) composed of bright red garnets and grey anthophyllite blades (Mg-rich amphibole), perhaps derived from former basic igneous rock.

A talk on cosmology by a visiting speaker rounded off a slightly different day!

The Pennine zone in the Lukmanier Pass, the Tavetschezwischengebirge and the Rhône Glacier

Day 10.

In complete contrast to the day before, we had blue skies and warm sunshine as we made a start on a day that was to combine geology with a bit of sightseeing and also get us back to Martigny by evening. The aims for the day were:

- Late Variscan granite, Triassic clastics and carbonates and Jurassic marks and mudrocks in the greenschist to low amphibolite facies, which had been metamorphosed and deformed in the Alpine Scopi syncline
- Liassic argillites with chloritoid, nipped between the Helvetic massifs near Curaglia
- Rhône glacier: mylonitized ice

Locality 1

We started off at the north end of a snow shed 'gallery' by the lake at the top of the Lukmanier Pass. The basement here is a Permian granite batholith, the Medelser granite (see Figure 18). This is covered by Trias and then Bundnerschiefer, which have all been compressed and show various deformation styles. Here the Triassic unconformity goes over an anticline, a syncline and a flat belt. The top of the Trias is also very uneven since the evaporites and the Bundnerschiefer are affected by the underlying basement morphology.

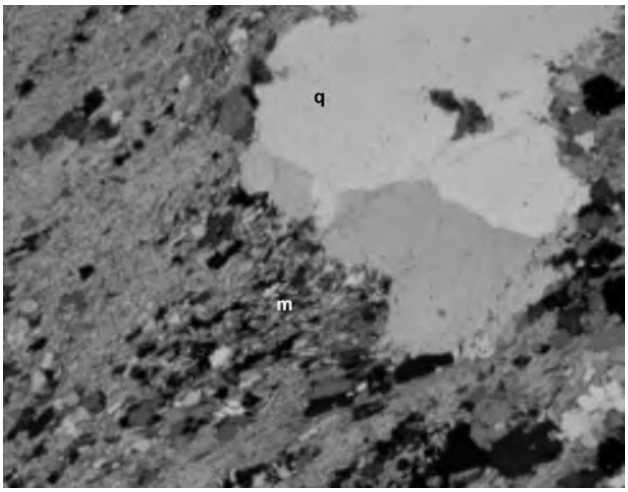

Figure 18. Photomicrograph of alpinized Late Variscan (Medelser) Granite. By the snow gallery, north entrance, Lukmanier Pass area. m - muscovite-rich pressure shadow; q - deformed, subgrained quartz phenocryst; crossed polars (xpl)

This particular area is the Scopi syncline; the axial plane dips north in a reverse, or back-thrust, arrangement with respect to the main Alpine structures. On the east side of the road an exposure of the Medelser granite shows that it is sheared into a mylonite in places. The basal sandstone of the Trias is a very pure, orthoquartzite (similar to the bed with dinosaur footprints at Salanfe) and this is intercalated with the sheared granite. Above the gallery and a hundred metres or so to the south, there is an exposure of anoxic, graphite schist, part of the Bundnerschiefer, with pyrite, chalcopyrite and zoisite.

Locality 2

From here we drove north down the valley through the Gotthard granites to the village of Curaglia. Here we are at the junction of the Aar Massif to the north and the Gotthard Massif to the south. Parking in a side turning we walked back down to the main road where we could see the argillaceous Liassic rocks exposed; they are almost vertical where they have been squeezed between the two massifs. They are approximately the same age as the black, graphitic schists at the previous stop but the metamorphic grade has now dropped as this is further north. They are characterized by minute black porphyroblasts of chloritoid which (with the aid of a hand lens) are seen to stand out from the pale coloured schist.

Looking across the valley the massifs were conveniently picked out by forested areas whilst the Lias was covered in grass and dotted with chalets. This line of Lias forms a tectonic belt called the Tavetschezwischengebirge. This is analogous to the Chamonix 'syncline' between the Aiguilles Rouge and the Mont Blanc Massifs (Figure 19).

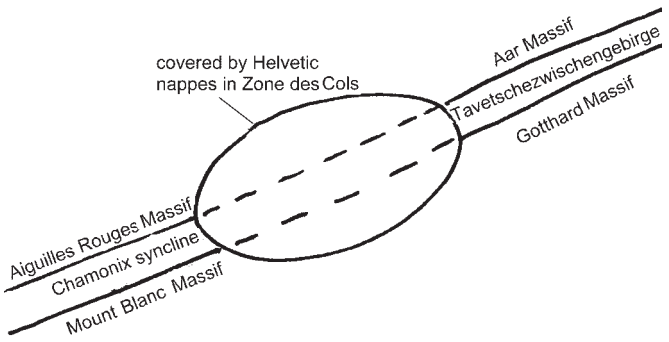

Figure 19. Relationship between Chamonix 'syncline' which lies between the Aiguilles Rouge and Mont Blanc massifs, and the Tavetschezwischengebirge, which lies between the Aar and Gotthard massifs.

From here we made out way through Disentis in the valley of the Vorder Rhine, over the Oberalp Pass, through Andermatt and over the Furka Pass to the Rhône glacier. Apart from being a delightfully scenic drive, with jagged peaks above U-shaped hanging valleys, we also crossed the watershed between two of Europe's largest rivers, the Rhine, flowing northwards to the North Sea, and the Rhône, flowing south to the Mediterranean.

Locality 3

The Rhone glacier is a tourist honey pot and includes an 'ice grotto' where you walk into an artificial tunnel in the glacier and can have your photo taken, complete with a chap in a polar bear costume. However, there were some more interesting points:

- Originally circular air bubbles sheared out by ice flow
- Ice recrystallised into larger, interlocking crystals
- An upper surface covered in debris, from dust to boulders, that gave it a distinctly grubby appearance
- Crevasses on the dirty 'snout' filled in with startlingly white, newer snow.

In the shop we found postcards, which showed another aspect of the glacier - retreat. The glacier currently ends at the mouth of a hanging valley around 500m above the main valley. However, old postcards show that in the early part of the 20th century it reached down to the main valley floor and in the middle of the 19th century it extended well down the main valley (Figure 20).

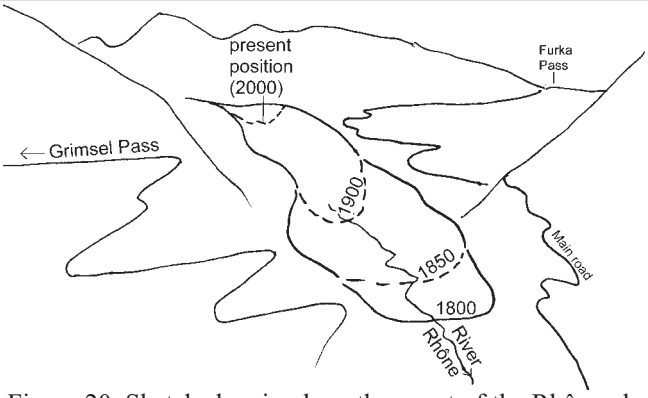

Figure 20. Sketch showing how the snout of the Rhône glacier has retreated since 1800, back up the main valley until 1900 when it reached the foot of the valley side below the hanging valley, then, during the 20th century, up to its present level in the hanging valley.

Locality 4

Finally the group stopped at Leytron, on the north side of the Rhône valley, a locality that had been missed out on the drive from Martigny to Brig because of lack of time. Here in the Liassic calcareous shales, alpine deformation has stretched and boudinaged belemnite fossils and pyrite crystals have pressure shadows.

A meal together in Martigny rounded off the final day and the next morning the group made its way, via a short stop at the old salt mines in the Triassic evaporites at Bex, to Geneva airport.

On behalf of the OUGS members who enjoyed this trip I would like to thank Dr Bill Fitches for his inspiring and energetic leadership (particularly on the sub-horizontal slopes), for producing and describing the photomicrographs and for carefully checking the draft and filling in the gaps during the 'long winter evenings' whilst he was fracture logging in Libya. Thanks also go to Jan Ashton-Jones for the hard work she put into the planning and logistics. I am grateful to trip participants Isa Adams, Philip Clark, Martin and Jenny Elsworth and Rob Tripp for their contributions to this report and to Ted Smith for collecting samples and arranging for production of the thin sections.

References to the Alps in Open University course texts:

S236, Block 3 Internal Processes, Section 14, An Alpine Case Study.
S339, Block 4 Continental compression, Section 2, The Western Alps: structural techniques; Section 3, Deep Alpine Structure. Block 5 Deep and Early Crustal Processes, Section 3.2, The Ivrea Zone: a tectonic slice in the Alps.

Branch Reports for 2000

East Anglia

This year not all our trips went to plan. A day trip to Bradgate Park in September had to be postponed until next March due to the petrol shortage. The weekend trip to Dorset in the Spring had to be postponed as well due to health problems of the leader. In October Dr Gareth George did take us to Dorset but the weather was interesting! The tide had two levels, high and extremely high. I do not think any of us have ever visited Lulworth in such driving, almost horizontal, rain and wind.

The Branch had five day trips. In January Dr Simon Kelley repeated his Building Stones of Cambridge walk. There are some superb examples of local building stones to be found and some interesting more exotic ones. Odd stares and comments were provoked from passers by as we stared at the ammonites in the floor of the main shopping arcade. March saw us back in Cambridge at the Sedgwick Museum for a guided tour led by the curator Mike Dorling. The material held by the museum is very comprehensive although the layout is rather old fashioned but will not be so for long as it is being refurbished. We were asked what we, as students, would like to see in the museum. April saw some of us off to Walton on the Naze led by me. We offered bird watching in the afternoon. In June we went to the North Norfolk Coast between Wells and Weybourne, led by Dr Julian Andrews, who had talked to us the previous year; this was Holocene geology and bird watching. Dr Andrews is interested in very recent coastal features including the new plans for coastal development in Norfolk. Very interesting, informative and different. The last trip this year was in November. In the morning Dr Jill Eyres took us to the Cretaceous Seaside near Leighton Buzzard, Mundays Hill Quarry. The idea was to have looked at the sands and the sedimentary structures but AGAIN the weather was against us. Although the quarry was not completely flooded, certain areas were and we were warned that the clay was on the move. It did not start raining until we had rejoined the cars. The afternoon was spent at Walton Hall where Dr Dave Williams explained how he was running a fossil replica 'factory'. We were then shown around and were able to make our own replicas to take home.

The Branch held its day of talks in February. Dr David Norman talked about recent developments in understanding dinosaurs. After coffee Dr Peter Sheldon talked about Evolution and Environmental Change - Explaining a Paradox. After a buffet lunch Dr Dee Edwards talked about the OUGS trip to the Auvergne. The day finished with the branch AGM. During the year two events were arranged for Rockwatch. The children were taken to Walton on the Naze and a Rockwatch Roadshow was held near Bury St Edmunds where several activities were laid on for the children, including fossil replica painting, earthquake measuring, dinosaur modelling, a timeline and quizzes.

Wendy Hamilton

East Midlands

A very successful Snowflake weekend was led by Phil Ingham to Derbyshire and Alderley Edge. In Derbyshire, Windy Knoll to be precise, on the Saturday the snow gave us white-out and it was deemed too dangerous to stay out, a retreat to Buxton and local visits and slide shows followed. Dinner was memorable. On the Sunday a brilliant morning saw scraping of cars and a journey to Alderley Edge via a couple of snowy photostops to copper, sandstone and legends of wizards. Alderley Edge is, of course, where King Arthur and his knights are hidden sleeping in a cave waiting to rescue Britain when the need arises.

The AGM in January was held at the BGS with members' lectures afterwards. The Branch Dinner at The Otter in Kegworth had half the previous number, as did the Basic Geology Day to Black Rock and the National Stone Centre.

Symptoms of the decline in attendance started early in the year when, in the month of January, 40% of the people who said they were interested dropped out of the Easter trip for one reason or another. Combined with the distinct unavailability of affordable hotels and the distances of travel that were projected the cost element of this trip was communicated to the participants. It proved to be too much for many people as we had set a notional limit on the cost of our Easter trips way below the level envisaged for this trip, so this must have been a determining factor. We received various suggestions that we should find B&B accommodation and meet in a pub for meals but, apart from this being an administrative nightmare, the ability of pubs in a remote area of the North East of Scotland being able to rustle up food for a set of tired geologists at Easter was pushing the bounds of practicality. It is bad enough getting people out into the field from one building, let alone several scattered over several miles of Scottish countryside.

A visit to Iron Mines in Northamptonshire and another to the coast of the Humber elicited some response but we were here let down by a tourist office employee subtracting rather than adding an hour to make BST out of GMT and allowing us to miss the tide by two hours. It had been hoped to show the structure of the Humber Estuary from the Humber Bridge, but time did not permit this. Since then we have bought a set of programs which calculate not only times but structure of tides for the British Isles and the Channel.

We tried an August quarry trip this year - attendance was reasonable but the communication between the quarry managers was not. Our revision day attracted only four bookings - despite coverage in the National Newsletter and forms made available at Summer School - we received not one of these back - wonder where they went?

Chris Arkwright's trip to Mam Tor was on the day that weathermen predicted that the heavens would open - in fact we had a morning in sunshine and lunch in Treak Cliff. Just as we were finishing the ominous pitter patter of raindrops heralded the stuff which caused flooding misery all over the country.

Lectures throughout the year concerned the BGS Photographic record, the landscape of the Maya and a forthcoming talk on alluvial gold. The September lecture, coming as it did in the midst of the fuel protests, had to be cancelled.

Symposium was a joint effort between East and West Midlands with 157 full residents, 62 of whom stayed on over Sunday night. Of our 11 day visitors, 4 came for both days, 5 for the Saturday and 2 for the Sunday. 8 full length lectures and 3 shorter talks, these from members of Showcase, filled the weekend as well as Showcase - members of the Society who had taken their studies past the normal realms of their degrees. 20 displays were given and it gave a real insight into the expertise within the Society. Telford gave us superb catering and very welcome co-operation over four years to make this event the success it undoubtedly was.

Sadly just over a week after Symposium John Oxley, who was the chief technician, was found dead at home. Six members of the branch attended his funeral and donations were made to the British Heart Foundation.

During the Summer a two week camp was run in Cornwall to examine some issues of resources using S268 as a base. As originally conceived the notion of the camp was to allow people to enjoy geology without absenting themselves from their families as we have seen that geological field trips can be divisive. Over five years we have proven that it is possible to have geological trips which not only involve the family but make them want to come back; we positively welcome dogs. It is, after all, a family we are trying to cater for and not divide specialists and non-specialists. A total of 71 people and 6 dogs enjoyed the delights of Cornwall this year.

Trip attendance was not what we have experienced in previous years, leading to the cancellation of three events. The question which constantly comes up is why we are experiencing this decline? Is it because the emphasis on fieldwork has changed within the courses offered by the OU? We have seen field trip carrying summer schools reduced and the emergence of virtual field trips. Or could it be that within the branch we have shot ourselves in the foot by reducing the frequency and size of newsletters. This was done for cost reasons and some views that the

newsletters were getting verbose and that other branch members would not want to read reports of other people's views of events. Thinking back over the past ten years we deliberately increased the communication with branch members and saw attendance at field trips rise, now we have reduced them, attendance is falling. It is very tempting to ascribe this as a direct cause and effect.

This concludes the annual summary and also it is my last as Branch Organiser; next year it will be someone else. Also not standing for re-election are Colin Small, Rosemary Broadey and Sandy Colby. The last eleven years have not been without their moments both memorable and less so, and the people met and places visited have been the most enjoyable in my life.

John Colby

East Scotland

The Branch AGM was held as usual in January, when a modest number of members braved the weather to assemble in Perth. At the meeting retiring Branch Organiser Paul Speak thanked Treasurer Angus Macpherson, Newsletter Editor Jenny Allan and Events Co-ordinator Doug Palmer for their work for the Branch. There being only one candidate to succeed Paul, I was duly elected, and my first task was to thank him in turn for all his efforts for the Branch over the previous few years.

In May we embarked on our most ambitious field trip to date, a week in Shetland, organised by Jenny Allan and led by Branch member Allen Fraser. He was ably helped by his wife Ann and by Ian Gray and Robin Hunter who drove the minibuses and impressed us all with their encyclopaedic knowledge of Shetland. Sixteen OUGS participants were joined by members of the Shetland Field Studies Group and we were blessed by five dry sunny days out of six. It would be invidious to try to list all the splendid localities we visited but just a few which stick in my mind are the Viking soapstone quarries at Catpund, the tombolo at St Ninian's Isle, pink sheared monzonite at Ward of Tumblin, a splendid example of boudinage at Voe, striped 'mint humbug' rocks at Laxo and breathtaking Valayre gneiss at Grutwick, chromite workings at Nikka Vord and talc workings at Clibberswick next to a black serpentinite beach and the huge phenocrysts in the Skaw granite beside the most northerly inhabited house in Britain. Then there was the impressive range of volcanic rocks at Esha Ness, including ignimbrite blocks two metres long, tossed to the top of the cliffs by sea and storm action to form an imbricated stack up to 100m inland and in Northmaven, where brightly coloured granites intrude earlier gneisses in ring-dyke complexes. There were lots of sedimentary rocks as well, amongst them a rare boulder of tonsbergite which has been positively identified as coming from southern Norway; the Exnaboe Fish Beds, aeolian dune bedding and finally a magnificent example of alluvial fanglomerates at Skottle Holm. Geology apart, there were plenty of other things to see, flora and birds, otters and seals, archaeology and the preparations for Up Helly Aa.

Our next trip was at the beginning of July, when a party of fourteen under the leadership of Dr Roy MacGregor discovered the secrets of the initially uninspiring-looking shore beside the Tay Bridge at Wormit and the wider view from the summit of Norman's Law. We examined a rhyolite plug and mixed flows of lava and wet sediments on the shore and viewed the serried ridges of hills marking the positions of the different lava flows and the faults cutting them.

The Branch's September trip almost fell victim to the fuel crisis but a quick round of e-mails established the determination of most participants to get there regardless; twelve people joined Professor Brian Upton at Melrose. Once again the theme was Carboniferous volcanic rocks. We examined tuffs cut by quartz-porphyry dykes in the Chiefswood vent and the underlying sanidine trachyte in Bowdenmoor Quarry; viewed agglomerates and collected riebeckite 'felsite' from the screes on the slopes of the Eildon Hills where the rain, which had been threatening all day, lasted just long enough to prevent proper enjoyment of the view from the summit. Lunch was an uncharacteristically civilised affair in a local hotel bar and we ended the day with a visit to the Kelso Traps and Smailholm Tower.

A group of fifteen celebrated the end of exams on a sunny October day in Glen Esk, where Dr Andrew McLeish led us on a stream (or rather river) section to unravel the succession in the Highland Boundary Complex in Glen Esk. We started on the Lower Old Red Sandstones and conglomerates and worked our way up the river and down the stratigraphy to the Dalradian phyllites beyond the boundary zone. Unfortunately the water level was high enough to cover some of the exposures which we had hoped to see, but there was a good enough range of rocks among the visible outcrops to give us some understanding of the complexities of the boundary zone.

Our 2001 programme is in the course of preparation, and we are co-operating closely with the West of Scotland Branch to avoid the clashes of events which have occurred in recent years and thereby provide a wider choice of trips for members of both branches. We are also working to establish what we hope will be mutually advantageous links with the Edinburgh Geological Society, the Geological Society of Aberdeen and the Highland Geological Society, initially by listing their events in our newsletters and welcoming their members to our events.

In conclusion, I would just like to thank all who have contributed to the Branch's activities this year: Angus, Jenny and Doug for continuing their sterling work; Paul for his much-needed and very welcome advice; to our leaders - Allen Fraser and his 'team', Roy MacGregor, Brian Upton and Andrew McLeish and to the members of our own and other Branches who have supported the Branch by attending the events.

Ann Burgess

Gogledd Cymru

In my second year as Branch Organiser we have seen an expansion on many fronts. After a successful AGM in Wrexham at the beginning of the year an envious audience was treated by our secretary Fred Owen to the delights of Hawaiian geology; we have also had some fascinating field trips covering both a wide geographical area and wide geological span of the North Wales branch region.

In March we looked at the extraction of Quaternary sand and gravels from a quarry near Mold, while in April Norman Harrison led us in looking at Quaternary glaciation at Nefyn on the wonderful Lleyn Peninsula enhanced by fine weather. Glorious weather accompanied us at Blaenau Ffestiniog in May, where we explored the contact between the Tan-y-Grisiau granite and surrounding metamorphic aureole under the guidance of Dr John Wadsworth.

A fine but windy June day saw us making the trek across the Wirral sands looking at the Hilbre Hydrocarbon Reservoir rocks while unsuccessfully scouring them for dinosaur footprints! Our leader, Geoff Willett, took us to both Little Eye and Hilbre and treated us to a remarkable imitation of the seals that colonise these islands! July saw several of the committee and branch members attending the Telford Symposium (well done East and West Midland branches for a highly enjoyable time).

The September trip to revisit the Carboniferous limestone at Pant Quarry at Halkyn was postponed because of the fuel crisis but successfully took place at the beginning of November. We allowed more time to examine the rock than view the quarry operations and many of us bought back our "trophies" - lovely pieces of fluorspar veins and various fossils.

By October and our trip to the beautiful Glyn Ceiriog valley, the weather had changed ... and how!! Sue Hughes valiantly led us to exposures of Ordovician mudstones and slates but our vision was obscured by our sub-aqua suits! Reluctantly, after a warm and very welcome pub lunch and watching the rising waters of the Ceiriog, we abandoned the trip.

This year has seen many of us increasing our geological interests beyond the boundaries of the branch. Fred Owen has produced an excellent geological trail around Styal Country Park (near Manchester) which I can highly recommend as both interesting and easy to follow. It is also thanks to Fred that we are now liaising closely with the NWGA (North Wales Geological Association) - where members of each are welcomed at each other's events, a mixture that has proved to be highly successful, and Sue

Hughes and Geoff Willett are liaising with other GAs and Geological Societies. For myself, I am involved with NEWRIGS and a trip in July saw GCOUGS and NEWRIGS link up to begin a geowalk along Offa's Dyke as well as an informative trip to a quarry near Wrexham in October.

We also linked up with NWOUGS in September to help with a well-attended Revision Day and I would like to thank Geoff Willett for his input on the day.

Next year's programme is almost complete and membership of the branch is steadily increasing. The field trip weather has been generally good and the geology excellent. I think that the committee of Sue Hughes (treasurer), Fred Owen (secretary), Alan Seago (hardworking tutor) and Geoff Willett (newsletter editor) can be pleased with all their efforts this year. Without them, it would not be half as much fun and I cannot find enough of the right words to thank them. I would also like to thank the members and leaders who support us on our trips - you are the people who make it worthwhile.

Wendy Owens

Ireland

Branch membership currently stands at 44 plus 7 family members which is slightly down on last year. This has not affected participation on field trips which remains good. The Branch AGM was held in the OU regional office in Belfast in January and was very well attended. The Branch committee was extended to 10 members which bodes well for the future of the branch.

The first field trip of the year was in February when Bettie Higgs celebrated her birthday by taking us for a geowalk to Galtymore in Tipperary. Unfortunately the weather was not great in that a thick fog enveloped the mountain and not very much geology could be seen. However, some people did make it to the top and two valuable lessons were to be learned from the day, 1) Be aware of your capabilities. 2) Be prepared for bad weather.

In March Susan Pyne took us to Killiney. The morning was spent on Killiney Hill where we could appreciate the topography of the surrounding hills. The afternoon entailed a walk along the beach where we found some spectacular andalusite crystals. In April Gerry Stanley and Eibhlin Doyle took us to make our fortune on the Dodder with a gold panning day. This was very enjoyable and we all got some gold, but alas not enough to retire on.

Fermanagh and South Donegal was the destination for our only weekend trip of the year. Patrick McKeever of the GSNI gave us two days of spectacular geology. On Saturday we saw the junction of the Ballyshannon Limestone and the overlying Bundoran Shale. We then went on to the Mullaghmore Sandstone which contains three broad facies: shales / siltstones with interbedded sandstones; bedded sandstones with minor shales / siltstones; major, thick channel sandstones with southward dipping cross-sets. The next stop was Streedagh Point where the coral *Zaphrentis* has to be seen to be believed. We then moved on to Drumcliffe Church of Ireland graveyard (the final resting place of W B Yeats). This stop gave an opportunity to examine the slopes of Benbulben which is capped by the Dartry Limestone which, together with the Glencar Limestone, makes up the cliffs. These overlie the Benbulben Shale, the MulIaghmore Sandstone and Bundoran Shale at the base. The final stop of the day was to examine the Moinian rocks of the Ox Mountains. The first stop on Sunday was at Glennasheevar quarry to see the Meenymore Formation which consists of mudstone and thin limestones. The next quarry was at Slisgarrow where the Garrison Sill (of Palaeogene age) can be seen. At this location both the upper and lower contacts with the Meenymore Formation are visible. We then visited the Shannon Pot which is the source of the Shannon. The day ended with a visit to the Marble Arch caves formed within the Dartry Limestone.

In July we visited the Newtownards Lead Mines and Coalpit Bay with Dr Norman Moles. The lead mines employed about 400 people in their heyday in the 1850s and, while the shafts are now inaccessible, the visual impact the mines have left behind is striking. The slagheaps provided many samples containing galena and chalcopyrite crystals. At Coalpit Bay within a few hundred metres we examined Carbonaceous shales of Ordovician age which contained abundant graptolites, a plunging anticline in Silurian greywackes with interbedded volcanic ash layers (bentonites), spectacular sole structures on the base of turbidite beds, a lamprophyre dyke (or sill) intruded in the Devonian and Pleistocene raised beach deposits.

In August we went to see the Quaternary geology of Co Meath with Robbie Meehan. We met at Trim Castle which is the largest remaining Anglo-Norman castle in Europe and was the setting for most of the filming of Braveheart. We had a look at the bedrock beneath the castle walls before moving on to the Trim Esker which is part of a series of Eskers in this part of Ireland. We then went to look at the Galtrim Moraine and the Hill of Tara. The day ended with a visit to Slieve na Calliagh to look at the bedrock geology, erratics and roches moutonnees. Unfortunately, our October trip to Anglesea had to be postponed till next year,

This has been a very busy year for the committee with organizing field trips and putting next year's Symposium together; I would like to thank them for all their efforts. I would also like to thank all our leaders for their efforts and for giving their time so generously, without which the branch could not function.

John Leahy

London

Once more the London Branch has had a very active year with ten talks (ranging from updates on continuing work at Pisa and Boxgrove given by John Burland and Simon Parfitt respectively, to recent work on Insects in Amber by Andrew Ross); nine day trips (from visiting the Kellaway Beds and Oxford Clay with Neville Hollingworth to another couple of highly successful Geowalks with Brian Harvey); and two residential trips: Sue Hay took us to Sidmouth for our Winter Weekend and in the Summer Andy Gale led a trip to Northern Spain. In addition to all of the above we had a successful Branch AGM and Dinner with our guest Dee Edwards. The last Revision Day for S260 was again held at Egham, before it becomes SXR260 next year.

The Branch has been instrumental in publicising the whole Society in two areas this year. We organised and manned the Recruitment Stall on Sunday evenings at Reading University along with members from Oxford Branch. This was quite a sad occasion for us as we have been doing this for some twenty-plus years now and this was the last time that it was held at Reading as its replacement, SXR103 is to be held at Sussex University from 2001. The other opportunity came at the Earth Alert conference at Brighton in May. We are extremely indebted to three of our members, Sue Vernon, John Wade and Peter Franklin, who gave up much of their time for this.

I need to thank all of the Committee for their hard work, commitment and support on behalf of the Branch as well as from myself, for without them there would be no trips or talks taking place. I am not going to single out anyone in particular because we have all worked together as a team. In my report last year I stated that it was good to have a dynamic Committee (in more senses than one) and to that end I have decided that it was time that a new Branch Organiser is needed. Indeed I have been the Branch Organiser for three years and on the Branch Committee for eleven years, so I feel that it is high time I stepped down! I feel that I leave the Committee and Branch in good shape and still the largest branch. While it is so active and diverse it must go from strength to strength.

Polly Rhodes

Northumbria

This year has seen some remarkably lively meetings in a variety of weathers. Branch membership is slightly up on last year, and more people attend field trips. Several field trips, such as the one to the Cheviot Hills and Jim Gallagher's excursion to the Hudeshope Burn in Middleton-in-Teesdale, have drawn people from as far afield as south Lincolnshire, Leicestershire, the north west and south east Scotland.

The AGM was held at the University of Durham in January, when we were fortunate enough to secure Professor Howard Armstrong as a speaker. One of Prof Armstrong's interests is the deep structure of the Iapteus Suture and he led us deep into geophysical territory with his interpretations of seismic surveys – a talk as fascinating as it was complex. After the AGM we had refreshments in the common room, which gave us all a chance to welcome newcomers, greet old friends and catch up on the Branch gossip.

We joined with the North East Geological Society for their winter lectures, and our first outing of the year was to Howick Shore at the beginning of May. The shoreline between Boulmer and Craster is magnificent, both geologically and aesthetically and the opportunity of seeing fossils, including dinosaur footprints, *in situ* is very exciting. We were treated to bryozoans, *lepidodendrons*, pectens and a wide variety of trace fossils – worm burrows etc.

In Northumbria we are lucky to have one of the best examples of Yoredale Cyclothems in the United Kingdom, and we took advantage of this with a joint field trip with S260 to Haltwhistle Burn, led by the irrepressible Dr Paul Williams.

Linda Lane-Thornton

North West

Our January lectures this year were held at Lancaster University where, under the general heading of East meets West, 'The Stratigraphy and Structure of the Carboniferous West Coast', was given by Dr. Colin Patrick (Lancaster University), followed by, ' A walk down the Jurassic East Coast' by Alistair Bowden (Scarborough Museum). The branch AGM was held on a Saturday evening in February and was followed by a dinner at the same venue.

The first outdoor meeting in March was an Urban Mapping exercise in Liverpool. The route took us around the 'Centre' where we visited actual outcrops of 'living rock' (mainly Permian sandstones) on which lie the foundations of both great Cathedrals and finally ending at the location of the 'Pool' which gave Liverpool part of its name. It was quite a revelation to see so much naturally outcropping rock in the heart of the city. As in the past few years we visited the Glens of lngleton on our annual 'Geology for Beginners Day'. Basically aimed at those embarking upon S103 and S260 the trip still proves popular for all comers. Each year we seem to find a little something new which adds more to the understanding of the area. Our May field trip was to Cheshire to look at the deposition and mineralisation in the Triassic sandstones of Alderley Edge. Good weather accompanied this trip which was well attended. The Island of Mull was chosen for the end of May long weekend 'Mullenium Trip', (yes, the pun is intended). The major theme of this trip was to hunt zeolites and identify their complex make up and structure.

June provided a further long weekend exploring the Dent Fault and Cross Fell lnlier. The plan was to look for evidence of this major fault in the area of Sedbergh and Cross Fell and see the effects of the Silurian meeting the Carboniferous. A joint venture with the Yorkshire branch in July found us in the area of Crummack Dale near Ingleton. Apart from the interesting geology in the form of the Norber Erratics, Marine Transgression and 'Moughton Whetstone' (concentrically coloured banded rock), the visit will be remembered for the onslaught of the local midges which drove us off one of the locations.

In August, two branch members undertook a field trip which followed a route that was feasible for those who may have difficulty with more arduous terrain. This was in the vicinity of Chapel le Dale, Yorkshire, and centred upon the unconformity between the lngletonian Ordovician rocks and those of the Carboniferous limestones. At the beginning of September the S267/S268 Geophysics weekend was held in Penrith, Cumbria, and a number of members of the NW branch committee were greatly involved in the organisation and support of this event. Later that month we were to have visited Derbyshire for a day of Peak District Mineralisation; however, this coincided with the fuel crisis and had to be postponed. It is hoped to run this field event in our 2001 programme. The events in September ended with a very successful Revision Day held at Chester which was a joint venture with the North Wales branch. Some 38 students from a wide area booked for the day to brush up on the topics relevant to S260 and S269, all of whom expressed the opinion that it had been a worthwhile exercise. It was intended to hold a field weekend at Llangollen during the month of November but, regrettably, it had to be cancelled due to the lack of members wishing to attend.

To round off the year's programme our final winter lectures will be held in December at Middleton when the topics will be 'Glacial Sediments and Landforms of Jostedasbreen in Norway' by Dr. S Suggit (OU and Edge Hill College), 'Hawaii' by T Barrett (OUGS North West) and 'Madeira' by A Diggles (OUGS North West).

Our current membership stands at 250 which is more or less the same as at this time last year, the number of members lost being made up by new members. We have enjoyed another year of varied, informative and interesting geology with reasonably good weather for most of our field trips, which I hope have been enjoyed by all who have taken part. My thanks for this go to Chris Arkwright our field and events coordinator, the branch committee, leaders, lecturers and all members who have contributed throughout the year.

Alan Diggles

Oxford

The Oxford Branch membership continues to rise – there are now about 140 members, a large number of whom regularly take part in our varied programme of lectures, day trips and residential weekends. Our AGM was held in January at The Research Laboratory for Archaeology and the History of Art in Oxford. As last year, the attendance was good and we were pleased to welcome Society Chairman John Lamont to the meeting. Helen Craggs stood down as Branch Organiser after a very successful five-year stint. The new Committee is slightly larger than before, with some new faces.

The year's first lecture was held in February at the University of Reading when Jerry Workman gave a most interesting talk about the Geology of Mars. This was geology at a distance as the interpretation is based on information from space probes and, most recently, from Mars landers.

In April, John Downes led the Branch on a breezy day-trip in the Chilterns and Vale of Oxford where we walked over the chalk scarp at Beacon Hill and saw exposures in the Corallian sequence at Dry Sandford Quarry. On a hot day in May, we made our first visit to Temple Mills Quarry in North Oxfordshire. It is hoped that the Branch can go there regularly in order to survey and map the Great Oolite in this disused, private quarry.

A change from geology saw Branch members and others visiting Down House in Kent in June. This is the house where Charles Darwin lived and now houses the Darwin Museum.

Our Summer Weekend in July was led by Alan Diggles of North West Branch. We saw coastal geology in Namurian Sandstones near Morecambe and large-scale unconformities (Silurian to Carboniferous) in Crummack Dale. It was great geology, not marred by the indifferent weather.

The first John Souster Memorial Lecture was given in September at the University of Reading. Dr Dee Edwards of the OU gave an excellent talk on the volcanoes of the Auvergne. This geology is very complicated, but it is undergoing re-interpretation since the eruption of Mount St Helens, with which some similarities have been recognised. Also in September, we had another departure from geology on a day-trip to Stourhead in Wiltshire to look at its collection of exotic trees. However, the Park did contain *Ginkgo biloba* and *Metasequoia glyptostroboides*, both of which could claim to be living fossils.

Our final field trip of the year was in the Wye Valley and the Forest of Dean where John Downes led us on a most interesting weekend. After long spells of rain and country-wide flooding we had reasonable weather and only missed one location (under water). We worked up the sequence from the Lower Devonian to the Upper Coal Measures. We saw unconformities, incised meanders, an abandoned meander, and also an

outcrop of the rich Yorkley coal seam, still worked today in the Forest of Dean. We are looking forward to a Lecture in December to be given by Professor Peter Worsley of the OU on 'The Bretz Megafloods' to be followed by our Christmas Party.

Our thanks go to the leaders and lecturers who have willingly given their time and services and also to Branch members who helped with recruitment at Reading Summer School. I should like to thank Committee members whose hard work and support have helped in the smooth running of the Branch and the events. All these contributions have ensured that 2000 has again been a successful year for Oxford Branch.

Madeline Ettlinger

Severnside

Our year began with a combined trip with the South West branch to Almeria, South Spain. The trip was based on the one that we ran previously with Dr Bill Gaskarth. Linda Fowler had carried out a lot of research on some new places to visit but we also revisited some of the venues we had visited before. It was good to see the sun at that time of year but the temperature at night was distinctly chilly!

We held our AGM in February at the National Museum of Wales, Cardiff, when we appointed a new treasurer, Bridget Wood, and welcomed Anthony Bukowski onto the committee. After the AGM and lunch Stephen Howe took us behind the scenes of the Geology Department of the Museum and we had a fascinating insight into the storage and cataloguing problems that they have.

At the end of March we held our annual Introductory Day when we hope to initiate new students into the delights of fieldwork. We had a good number of new faces and Stephen Howe led us along the coast from Penarth to St Mary's Well Bay looking at the evidence of changing facies in the rock record. Good spirit was maintained despite having lunch sitting on a beach with hailstones raining on to our hard hats!!

In April Dr Geraint Owen led a trip for us to the Upper Swansea Valley looking at the Carboniferous Limestones and millstone grits and the deformation due to the Variscan Orogeny. Not many people came on this trip but those that did had an excellent day out in beautiful countryside. At the end of April we combined with the South West Branch and spent Easter in Pembrokeshire with Dr Bill Fitches. Normally we have our weekend trip on the early May Bank Holiday but, because of tides and because Easter was only the weekend before, we held it then instead. A good crowd spent a superb weekend staying at Nolton Haven looking at spectacular structures developed in the outcrops caused by the Variscan Orogeny.

At the end of June we held a Pre-summer school mapping day at Upper Soudley with Dave Green. Several members of the Wessex branch helped swell our numbers and a very useful day was had using our compass-clinometers and transferring the information onto a large scale map of the old railway cutting.

In July Dr Bill Fitches led another combined trip with the South West branch to the Western Alps. We were based first at Martigny, then Brig, then over the Simplon pass to Locarno and the final stop at Aquacalda on the Southern side of the Lucomagno pass. A number of members from other branches joined us including two from the Mainland Europe Group for a couple of days each.

In the beginning of September four of us spent the day with Dr Keith Moseley looking at the area above the Wye Valley and collecting sand samples. After lunch we weighed the sand, then sieved it and entered the data into the computer to display the sediment profile to show in what environment they were laid down. We joined forces with the South Wales Geological Association at the end of September when we went to Portishead. Dr Geraint Owen led this trip and we spent time looking at sedimentary structures in the Old Red Sandstone.

Our annual day of lectures was held in November at our usual venue, Chepstow Leisure Centre. Linda Fowler gave a slide show of our trip to the Alps and Dr Jason Hilton of the University of Cardiff gave two talks, one on his hobby of fossil hunting in the Cotswold water park and the other on fossil hunting in China.

I thank all the members who come regularly on our trips and hope they will continue to support the branch. I thank all the leaders who have given us their time and expertise, making the trips so enjoyable.

Jan Ashton-Jones

South East

The Branch has about 130 members, mostly from East Sussex and Kent but several from the Home Counties, Surrey, West Sussex and Essex. Our varied programme of activities this year has attracted OUGS members from many regions. A record number of people came to our AGM, so much so that it will probably be necessary to hire a larger room next year. The meeting was followed by a lecture from Dr Martin Heath on planetary systems, galaxies and nebulae. A dinner rounded off the evening very well.

Reigate Stone Quarries. This was a shallow underground visit to a small section of the Godstone Mine in the Upper Greensand of Surrey on the edge of the south-facing escarpment. We viewed the small entrance hole with great trepidation but spent an amazing three hours stooping through the low narrow tunnels. We listened to Paul Sowan of the Wealden Cave & Mine Society as he related mining tales at regular intervals around the labyrinth of tunnels. This was such a popular outing that we organised a second visit in August.

Our Spring weekend to Pembroke was postponed due to our leader, Dr Gareth George, being taken ill. John Jaggard kindly stepped in at the last minute to lead a trip to the Hanter & Stanner Igneous complex in Powys. It turned out to be a huge success. We climbed hills, looked at landscapes, noted the igneous rock types, the retrograde, gabbros and dolerites, limestones, various minerals and much more. We finished the long weekend with a day along the Mortimer Forest Trail at Ludlow where we found a few trilobites.

Our visit to Sedgwick Museum, Cambridge, in June involved a guided tour behind the scenes. There were some glorious fossils to be seen including a huge slab of Red Sandstone showing large mud-cracks with footprints and tail-drag of a contemporary small reptile. We went to the large chalk quarry at Barrington just outside Cambridge in the afternoon where Dr Adrian Rundle guided us to many of the fossils such as belemnites, brachiopods, oysters and sharks teeth. We also studied some of his large selection of microscope slides containing ostracods.

Peter Golding took us on a series of walks in the Maidstone area where we started the day at the Buckmore Park Racing Circuit to see Pliocene Lenham Beds which had filled solution-hollows in the chalk. Later we considered the origin of Sarsen Stones - the most obvious ones in this area being those which make up the ancient monument of Kits Coty. They are a non-porous sandstone with few impurities. Their enigmatic reputation arises from the fact that their origin is unknown and the stone displays no telling features such as bedding or sedimentary structures. Sarsen stones are always associated with chalk and those from some sites have root-holes in them. A possible mode of origin is as a silcrete. Another site visited with Peter was the upper Loose valley to an overgrown quarry containing karst features in the Hythe Beds. Peter is hoping that this could become a RIGS site and be cleared of some of the vegetation on the quarry face. Sadly the day did not finish with our customary café visit!

We had our annual Fun & Fossils at Folkestone for RockWATCH members. It was a lovely hot day as usual in the Warren which is internationally known for its fossils in the Gault Clay and for its geomorphology. Everyone was able to take home a bag full of fossils and both children and parents were glad to add to their collections. It is certainly one of the best coastal sites in the south east and you need to travel a long way to find scenery as impressive. The cliffs at Cap Gris Nez were easily visible across the Channel and served as a reminder that our next residential weekend was to take a closer look at them. (If only the weather could have stayed as gentle).

Several of us went to the Boulonnais region in North France for a DIY post-exam weekend in October. Despite the appalling weather and the non-compliant tides, we managed to see a fair amount of rocks, either *in*

situ as building stones, in museums and tourist offices or included in a town's 'water feature'. Yes - this craze has reached across the Channel as well. We started with a building stones walk around Marquise where we found some lovely examples of the Napoleon 'Marble' which is actually a variable Carboniferous (Visean) limestone. When polished it displays some truly marvellous features. On the beach at Pointe aux Oies, just north of Wimereux, the wave-cut platform was of Wealden / Purbeckian beds in which we saw the large ammonite, *Titanites*, and also structures which looked like huge diapirs. The Kimmeridgian cliffs at La Creche, north of Wimereux, looked impressive but access to the beach below was impossible due to the wind strength which prevented us from descending the cliff safely. Some of us are intending to return in the future when the tides and weather are more favourable.

It is now 10 years since it was decided that members in the South East would be better served by a more local group, rather than being joined to the large London Branch. We have had a continuing increase in membership over that period with fewer losses than had previously been the case. The Branch celebrated this event with a social gathering and lectures. Professor Rory Mortimore enthralled us with his tales of rock-falls interrupting the Trans-Canadian Railway in the Cascades and Dr Ed Jarzembowski told us about the evolution and survival of insect species over the last 400 million years.

The Geologists' Association held 'Earth Alert' A Festival of Geology, just inside our area at the Brighton Conference Centre in May. There were field trips, a lecture programme and exhibitions over a period of 4 days. Members of our branch were there, either helping with various stands or attending the lectures.

During the spring, I investigated the feasibility of holding the Symposium 2002 at an academic institution in this region. Wye College, Canterbury University and Brighton were possible contenders but did not meet the strict criteria.

One of our Branch members, Chris Martin, has been placing photographs of many of our events onto his Photopoint Internet page which everyone is welcome to visit. It makes a very good record of our meetings and I thank him for this service. I would like to express my most grateful thanks to our leaders, who have all given up their time for us with little reward, except to enjoy our usual enthusiastic company! Thanks also to the participants who make the outings so pleasurable and, of course, the Branch Committee who have taken a huge load away from myself.

Yvonne Cutt

South West

Our year began with the Branch AGM in January. During the morning we listened to two interesting talks: Dr Robin Shail from Camborne School of Mines spoke on the Variscan in West Cornwall and Jane Randle, OUGS Newsletter Editor, illustrated a talk on 'Aerial Geology' with her own aerial photographs.

A trip to Almeria in February helped some of us beat winter blues (although the nights were cold!) and at the end of the same month we held an Open Day to attract new members.

On 8th April Branch member Jane Anderson led a trip to the Crackington and Rusey fault area and during the Easter weekend we joined forces with Severnside Branch for a visit to Pembrokeshire, led by Dr Bill Fitches, based in Nolton Haven – a different slant on the Variscan, and some spectacular structures.

At the start of May, Gordon Neighbour and I led a pair of trips aimed at people taking S338: we went to Dawlish Warren on Saturday and Greencliff, near Bideford, on Sunday. There was a good attendance from outside the area and it became clear that it would be worthwhile arranging accommodation for this event in future.

Our annual 'Pre-Summer School' S260 trip to Widemouth followed at the beginning of June, and we were amazed at the amount of erosion on our favourite field sketch location, the big anticline at the south end of Widemouth beach.

During July another trip planned jointly with Severnside, and again led by Bill Fitches, visited the Western Alps. A number of members from other branches joined us including two from the Mainland Europe Group for a couple of days each.

Dr Robin Shail followed up his AGM talk with a field visit to the Helston area 'Folds, faults and granites – how are they related?' in September: we spent the morning south of Porthleven and the afternoon at Megiliggar rocks. Despite the fuel crisis a large number of people managed to get there!

At rather short notice we tried out an S260 revision day at the beginning of October, ably led by branch members (and S260 tutors) Roger Beck and Mik Markham. We are waiting for the post-result feedback to find out how successful this was! The final event was John Macadam's visit to the Padstow and Trevone area in November. During the year we held three indoor events, six day trips, a residential weekend and two overseas trips. We currently have around 135 members and 34 family members.

Linda Fowler

Walton Hall

We have had a varied programme of speakers and trips; and once again are very grateful for the use of the PRG Room in Earth Sciences. We have welcomed many new members, and visitors from several other branches. We try to keep up links with the Department and have had great support this year from our President Peter Sheldon and also Dee Edwards, Dave Williams, Mike Henty, and Gill Foulkes. Sam Aderson and Andy McMillan have also been great supporters. Thank you all.

We started the year with a talk from Peter Sheldon called "Cavities and fillings", which was an exploration of the brickworks in the area and the use of the holes left behind. Good stuff for S268 students and very interesting too. Our treasurer John Barrett talked about geology and medicine in February - a fascinatingly different slant on the subject. Our March speaker was Lorraine Craig from the Royal Geographical Society. She talked about her experiences in Greenland and was responsible for most of the audience wanting to set off there and then! In April, Nick Petford from Kingston explained to us why he does not believe in granite diapirs, and demonstrated his thoughts on granite emplacement. Mark Davies was due to talk to us in May, but he suggested that he stand aside as Andy Harris (ex-OU), currently working at the University of Hawaii, was in town. Andy described the volcanoes in Guatemala that he is working on at present. We were lucky to hear this! We also wish Mark all the very best in his new post at UEA. Mike Henty dazzled us all in June with a talk about quartz in its many forms, complete with amazing samples. In July Jill Eyers took the group to Thornborough, Coombes Quarry. I missed this, but it sounded very good! Joe Jennings talked oil in September; sadly I missed this too, but heard very good reports of it. In October, Tony Waltham from Nottingham Trent showed more slides in 40 minutes than I would have believed possible and entertained us all with stories of subsidence and caves. November saw Ian Parkinson from the OU talking to us about the Solomon Islands and LIPs - which I now know are Large Igneous Provinces. Ian is involved with an ODP leg gathering samples there. We enjoyed his slides and he almost convinced us that it was a hard life out in the field! December will see our usual social gathering coordinated by Linda McArdell. This will give us a chance to compare finds and show photos.

We also ran field trips and other events this year - the annual dinner was superbly organised by John Leadley who was very pleased with the 'deal' he negotiated! We were happy to welcome our National Chairman, John Lamont and his partner Caroline to the dinner. Sadly, and it was a shock, John Leadley died unexpectedly in September. We will miss him very much. I always enjoyed his quiet sense of humour and found him a calming influence! Our sympathies go to Joyce, his widow.

A group visited the GEOU Fossil Factory in February, and had a fine time thanks to Dave Williams. Andy McMillan from the OU took a group gold-panning in Wales in May - I'm told that the barn and the cooking were superb.Tom Miller led another trip in June, this time to Derbyshire to look at the limestones; again a successful trip. Our foray abroad this

year was to Brittany in July with Dee Edwards and Dave Williams. I did manage to go on this one and thoroughly enjoyed it - lovely rocks, lovely sun, fun company and great food and wine!

The branch was also heavily involved in Open Day, with cheerful volunteers entertaining small children, watching Plaster of Paris dry, and sampling the President's wine! Thank you all very much. I am not listing you all as there were so many and I would hate to miss anyone out.

The year has been busy for many of us with many changes. Our best wishes go to Pauline and Alan Kirtley and to Olwen Williams-Thorpe and Ian Rigby who all were married this year. We also send our sympathies to Linda McArdell on the loss of David after a long illness. Linda is now a co-opted committee member, and we are very happy to welcome her.

I will not be standing for re-election so would like to thank the 'official' committee: (alphabetically!) John Barrett, Susie Hall, Dot Hill, Pauline Kirtley, John Leadley, Linda McArdell, Tom Miller and John Stanbridge and everyone else who has supported the branch. There have been many others and, of course, those of you who come to the trips and meetings!

Jenny Bennett

Wessex

In another very busy year the branch has seen some highlights and several "firsts", all solidly underpinned by our usual mix of lectures and field events throughout our region. Support for our endeavours from the membership, various leaders and organisers has again made the efforts of our diligent and talented branch officers worthwhile. Heartfelt thanks to Peter Martin, Alf Tingey and Sheila Alderman for delivering the excellent events programme and branch newsletters in a timely and cost effective manner.

In line with our aims as a branch, "learning by doing – in the field" we are in no way different from other branches in that we also have fun. There is always laughter echoing around our venues, from such things as finding nice specimens of fossil *Halitosis* corals to some excellent after dinner stand-up routines during our weekend breaks.

Our AGM venue at Wool was again enhanced by the superb lunch provided by Doreen Smith and Sheila who also organised a posse of interesting lectures. Doreen herself spoke of her Frome Valley Millennium Project work, bringing geology alive for Dorset villagers and tourists. Jane Clarke shared her experiences of New Zealand with some stunning slides and John Chaffey gave us a bikini and trunks guide to the geology of Tenerife. Our main speaker, Professor Michael House, set us a few puzzles in the evolution of ammonites. Several members supported the day with excellent exhibits covering exotic rocks and minerals from around the world and some local fossil collections to die for. As ever, I was grateful for the support of the members in attendance, not least in keeping the formal business to an absolute minimum. It was also good to have the presence of our National Events Officer and Archivist, David and Elizabeth Maddocks, raising the profile of the work put into the society by the National Committee. Never one to miss an opportunity, Sheila booked Dave to give a lecture next year!

Happily all the branch officers stood for election and their services were eagerly and gratefully retained along with those of stalwart Ordinary Members, Mick Warren, Pauline Pearce and Debbie Tabner.

The first of our "firsts" occurred at this point, when Chris Phillips volunteered to set up our own website, linked to the national one with the assistance of Martin Elsworth. Chris has made an excellent job of this, utilising his skills for our benefit and taking our activities to a wider potential audience.

In February we met at a sun-blessed Hengistbury Head for an overview of the Tertiary Sediments and coastal sea defences in East Dorset, led by John Chaffey.

Another good friend of ours, Dave Green, led a superb weekend in the Malvern Hills in early March, teasing our own knowledge out of us in his indomitable style. Later in the month Jo Thomas shared her extensive knowledge of Dorset Building stones and quarries in a walk around Sherborne. Michael House led another brilliant trip to West Bay and Eype where the palaeontologists among us had a particularly good day, but everyone ensured that Michael's knowledge did not go untapped.

Our second " first " occurred over the Easter Weekend when we had our inaugural visit to Jersey. Brian Trimmer found us an excellent package deal and we were splendidly looked after by our hosts of La Société Jersiaise who took the time and trouble to organise an itinerary that included prehistoric as well as the varied geological sites of interest. They tell us that Guernsey is as good and so a trip is being planned there for next year when we hope we will renew acquaintance with Warren Hobbs, Deidrie Shute, Dr Arthur Hill, Sandra Maher and Richard Ellison.

We were "overseas" again in May when we chugged over to Brownsea Island with Dr Mike Cosgrove, who kept a large group in good order through his ability to explain the geology on view in a knowledgeable and informative style.

Our third "first" was something of a double as, in July, we had two trips on the same day! Tony Cross led one of Sheila's well organised trips into the West Sussex Weald and included a much clearer view of Gilbert White's country than we managed to see on a rain-curtailed trip two years ago. The other trip, less well organised by me, took us to the South Cotswolds with Neville Hollingworth, pure fossil hunting and some! Most of us did not want to go home and I nearly didn't – locked in the Quarry car park by Neville hurrying to catch a plane to the far east. Luckily, his wife trusted me to forget the combination as soon as I ended my mobile phone call. I can definitely think of worse places to be stuck for a few days though.

In September we had another stab at revision field trips for S260 students. Proximity of exams and tutorials on the day before, not to mention the fuel crisis, conspired to keep the numbers low, but Worbarrow Bay put on its best face for those who could make it. Jane Clarke and I hopefully got some useful points across, ably assisted by Alan Holiday from Weymouth College. A fortnight later we had another go, at Osmington Mills, another first class venue for exploring a lot of the sedimentary content of S260 with the added bonus of some nice Corallian fossils. With the small number of students and an abundance of OU experienced helpers it is certain some learning was consolidated for the exam. Next year we will perhaps try the venues as Introductory days instead.

We have recently returned from a visit to Barton on Sea, enhanced by the expertise of Paul Clasby who generously invited us into his home to view his collections. After a general overview Paul led us by the nose to find specimens of our own and to identify the subtle changes in sediments of this classic section.

To round off the year, we had a lovely window in the awful November weather when we went to Cranborne Chase, visiting Martin Green's farm set aside for the preservation of some wonderful archaeology and some interesting geomorphology of chalk downland. Martin showed us his skill in producing flint tools and we were honoured when Mr & Mrs Phil Harding (of Time Team) visiting the farm to check on their pottery kiln, joined us for lunch at the pub.

Some of us have taken advantage of the National Symposium and AGM events, well organised by colleagues from other branches. We are grateful also for the work of all National Officers in looking after the overall interests of the society and contributing to our success. To them and all our friends, old and new, we very much look forward to meeting again in the field.

George Raggett

West Midlands

I will start by paying a special tribute to all of the leaders and lecturers who have willingly attended our events during the year and given up their time for our benefit. Without their continued support it would be

almost impossible for the Branch to exist. After the concerns of 1999, when the numbers of members at field trips dropped to a level which caused us to ask whether some events were viable for the future, 2000 has been an excellent year. We took note of the comments provided during our member survey and were rewarded with good attendance throughout.

Our AGM was held on the 23rd January and we were pleased to welcome our President, Dr Peter Sheldon, who was asked to "sing for his supper". Peter gave a fascinating talk entitled "Evolution and Environmental Change: explaining a paradox". We were all green with envy as Peter revealed details of a rich source of trilobites which he studied for his PhD.

Our field trip season began on a brisk and breezy day in February when we visited the Malverns. Our leader was Dr Peter Oliver, Regional Director for RIGS in Herefordshire and Worcestershire. The trip was well attended and, sadly, due to car parking restrictions, we had to limit numbers and turn some people away. The geology was excellent. The bemused landlord of the Brewers Arms saw his best Sunday trade in years but asked that next time we give him a little notice before descending at lunch time!

March saw our regular feature - the S260 Beginners Day. A light hearted romp around the Ercall Quarries led in their own particular way by Ian Kelly, Jim Galvin and others.

Wales was the venue for our weekend trip in April, expertly organised by Rhiannon. Bill Fitches ably led us around Aberystwyth, Ffestiniog and other parts of North Wales. Bill knows all of the best places, which we realised as we picked our way amongst rows of scrap cars in a breakers yard to examine one particular exposure. If we had allowed Bill to give us the full tour our weekend would have stretched into Monday, such is his enthusiasm.

If you have never experienced a trip led by Ian Rigby then you have missed a treat. Ian led us around the Long Mynd on our YHA weekend in May. He was too quick for some of us on Saturday. Regrettably, we lost the convoy and had to resort to sitting in the sunshine enjoying a cool drink. Sunday's geology made up for lost time, however, as Ian dragged us to a special spot just below the Wrekin where he revealed to us the Rushton Schists (all 2 square metres of them!)

In June it was Galway's turn for the West Midlands experience as a small group, organised by Chris Tompkins and led by Dave Green, headed West across the water.

West Midlands members played a significant role at Symposium, leading and assisting with field trips. My thanks to all concerned.

Our final trip of the year was to St Davids in west Wales on one of the stormiest weekends of the decade. Charlie Bendall was our leader who gallantly braved the elements to provide a fascinating snapshot of the local geology. Sadly, the weather curtailed Sunday's activities but our accommodation for the weekend more than made up for any disappointment on that score. Top marks again to Rhiannon.

Finally, on this my last annual report as Branch Organiser, my thanks to all the West Midlands Committee and members who have assisted and supported me during the past 4 (I think) years - or is it lifetimes! This year, a special thanks to Rhiannon and Alun, both of whom have played significant roles and held the Branch together.

Ron Whitfield

West Scotland

The final year of the Millennium has been excellent for us in many ways with a good variety of field trips having been provided for our members thanks to the efforts of our Events officer, Lindsay, who gave us everything from the Big Bang at Our Dynamic Earth to a post exam weekend at Inchnadamph Field Centre. The renewal of our 'special relationship' with the East of Scotland branch regarding advertising and timing of events has added more variety to this year's programme and generally spoiled OUGS members in Scotland for choice. An encouraging sign was that the numbers attending has increased significantly with many coming from other branches.

February saw us heading to Our Dynamic Earth in Edinburgh where Dr Stuart Monro, Scientific Director, gave us a talk on how the project developed over the years and highlighted some of the problems encountered along the way. The following month we attended an evening visit to Glasgow University Observatory with Steve Owens giving twenty two of us a talk on our solar system and, as usual, the children in the audience asked the most intelligent questions. This was followed by 'oohs and aahs' in the planetarium. Just on cue the night skies cleared and we were able to view our moon's craters, Jupiter and three of her moons, then Saturn and her ring system through the telescope in the observatory. More 'oohs and aahs' and we all went home satisfied.

Professor Brian Upton of Edinburgh University and Dr David Stephenson from the BGS led us on a day excursion through the Upper Carboniferous / Permian of the Mauchline basin in April and in May we had our first weekend event of the year based in Elgin on the Moray Coast. This was an opportunity for members to meet and spend some time in the company of Professor Ken Glennie, of North Sea exploration and S338 textbook fame, and Carol Hopkins, whose research has done so much to bring the Hopeman Sandstone footprints to the attention of many, resulting in Ken having to rethink his theory on Zechstein transgression. Bob Davidson of Aberdeen University led us on a Devonian fish hunt and evening talks by Sinclair Ross of the Highland Geological Society on beach erratics and Richard Oram on the Picts rounded off an excellent weekend.

The summer months had us visiting Tyndrum lead mines in June with Dr Iain Allison of Glasgow University and the following month we joined the East Scotland Branch in Fife with Dr Roy McGregor for Wormit Shore and Norman's Law. The Giant's Causeway in thirteen hours via the SeaCat service from Troon in August was executed with military precision by Lindsay and proved to be a very successful outing, every one of us agreeing that it really has to be seen to be fully appreciated. In September and October some of us joined East Scotland Branch trips to the Eildon Hills at Melrose in the Borders, again with Brian Upton, and the Glen Esk Fault with Dr Andrew McLeish, OU tutor and raconteur extraordinaire.

Our final event of the year was a stay at Assynt Field Centre, Inchnadamph, in the remote northwest in the company of Dr Iain Allison for what was billed as our post exam weekend. Miles from the trappings of millennium life, except of course for the microwave oven, television, video, central heating, showers, hotel, etc, we experienced the Lewisian basement, Cambrian Pipe Rock, and thrust planes aplenty. Iain is something of an expert in this area having brought many undergraduates from Glasgow over a period of many years to do their practicals. Incidentally the hotel displays the guest book signed by Peach and Horne and other prominent geologists on their trip to these parts in 1912. The book was recovered in 1993 by the above mentioned Roy MacGregor and Sinclair Ross who arranged to have it displayed in the hotel. Also included, at no extra cost to participants, were horizontal and vertical rain, gale force winds and peat bogs with large deep holes which were constantly inviting you to 'drop in'. We all had a great weekend, with the weather on only one of the days making fieldwork impossible. Undaunted we made off in the cars to look at the Lewisian road cutting north of Scourie and visited Achmelvich and a Scourie dyke. The Monday dawned on an idyllic Highland day, as do all final days on trips to the Highlands, clear skies and windless; revitalised we donned walking gear and trekked over the hills to inspect the Glencoul thrust plane close up. A perfect end to the year's activities.

Changes in the Branch committee this year include the departure of our Events Officer, Lindsay Hamilton, in October. Lindsay has been the backbone of our branch for many years since taking over as Events Officer in 1996. Her endeavours in organising many great days out over the years have been appreciated by all of our members, and on behalf of everyone I would like to say a big thank you. Also, due to other com-

mitments, our treasurer, Jack Canavan, left us half way through the year with Susan Clark taking over the post.

Here's to a good 2001 to all OUGS branches.

Stuart Fairley

Yorkshire

The year started with our AGM on 29th January at the Yorkshire Museum which was followed by a talk by Joe Jennings on oil exploration. The following Friday about 20 members went to Llandudno for an enjoyable weekend looking at the local area and the Bronze Age copper mine on the Great Orme.

On the 19th March Jean Sampson lead a building stone walk around Sheffield. This included the older civic buildings built from locally quarried stone, newer ones faced with imported stone as well as recently developed public areas using limestone and sandstone benches and the fascinating millennium park. In April one of our members showed us round local outcrops of the Magnesian Limestone in his area of Ripon. The May bank holiday weekend saw us in Moffat for the first of our gold panning trips. The National Championships were taking place (joined by one of our party) in Wanlockhead. The August bank holiday saw our second gold panning expedition, this time to Wales where the weather was good, avoiding the tornadoes on the coast.

On Easter Monday and Tuesday several members helped with the Yorkshire Dinosaur Coast Project by running a geological activity at the event at Scarborough and Whitby. Nearly 3,000 visitors attended the two days. I would like to pass on the thanks of the Dino Coast organisers to those who helped make it a success.

On the 3rd June low cloud enveloped Coldstones Quarry. We could not see the far side or the bottom, so we toured round in the Land Rover to see where the lead veins and the old workings cut across the new limestone workings and to raid the spoil heap. On the weekend after the Symposium we had a joint field trip with the North West Branch, starting from Austwick to see the Norber erratics and Crummack Dale. This time we were plagued by midges on an unexpectedly hot day.

Unfortunately, due to petrol shortages, we had to postpone the September visit to the Yorkshire Moors and coast. On the 27th October six of us joined Alan Stollery in Conistone Wharfedale. This time we had an exceptionally wet day. On 4th November the railway problems reduced numbers going on a joint visit with the East Midlands to see behind the scenes at the Natural History Museum. We still have our winter weekend in Edinburgh to took forward to at the beginning of February.

I would like to thank all our leaders and the committee members for making my first year as organiser such an enjoyable and rewarding one.

Barbara Norton

Book reviews

Geoscience: Understanding Geological Processes by Dee Edwards and Chris King, 1999, Hodder & Stoughton, 256 pp, £25 (paperback) ISBN 0340688432.

As it states in the introduction, this book is aimed at a wide audience ranging from students to teachers and, as such, is an introductory level entry into the topics of geoscience. Even so, it brings together many concepts only found at higher levels in a manner that is easy to read and understand. As an OU student I have found it contains many tried and tested details and figures which are familiar from OU courses.

The first chapter gives a brief introduction to the concepts of earth sciences ranging from the formation of the universe to expansion theories and Earth systems, cycles and their relationships. I thought parts of this were a bit dry and heavy for a beginner; however, it does give a good basis to the remainder of the book.

The book brings together many of the topics which are taught as separate subjects by the OU i.e. geology, physical resources and the environment. This was very pleasing as their relationships can more easily be seen this way. The case studies at the beginning of each chapter are interesting and generally provide a good lead into the contents of the chapter. I did find it rather annoying that answers to the questions at the end of each chapter were not provided.

To conclude, I found the book covered all the major areas of geoscience that would be expected at this level, in a clear and easily read format. I felt that it would encourage a beginner to look further into the subject. In some areas I would have liked a little more depth, however, it is an introduction and provides a good grounding. One disappointment was the price which at £25 may put off many interested students and amateurs.

Pam Sidgwick, continuing Earth Science student

Fossils & Evolution by T S Kemp, 1999, Oxford University Press, 284pp, £19.99 (paperback) ISBN 0198504241, £47.50 (Hardback) ISBN 0198503458.

T S Kemp is Lecturer in Zoology and Curator of the Zoological Collections at The Oxford University Museum of Natural History, and Tutorial Fellow in Biology of St John's College Oxford.

I thoroughly enjoyed reading this book. As my principal geological interest is in palaeobiology the title was guaranteed to attract my attention when it appeared in the list of 'reviewers wanted' and I was not disappointed.

The book brings together the various interpretations of the fossil record and the theories of the mechanics of evolution and the extent to which they support, or contradict, each other. The discussion is wide ranging from Darwin's 'Natural Selection' and Mendel's work on genetics, (memories of S365!) to isotopic dating and molecular development genetics.

The author discusses the strengths and weaknesses of the various theories and recognises that different explanations may fit different circumstances, rather than trying to put every eventuality into one box as supporters of some theories attempt to do.

I read the book 'cover to cover' and found it followed a logical sequence, with terminology and theories explained; therefore detailed knowledge or reference books are not necessary to follow the discussion, although some background understanding of the subject is needed.

The book is well indexed and, as the discussions include many theories I have met in OU Earth Science and Biology Courses, students of those courses, especially S365 and S269, will find useful additional information. Where a subject is repeated the page number of the original discussion is given (I missed the relevant words being in bold except where it is a chapter or paragraph heading - but the OU do spoil us, don't they?).

Black and white photographs, drawings, and diagrams are used to support the text, and they helped me to understand the arguments (with some of the more complex arguments I need all the help I can get).

The review on the cover concludes, "This textbook is suitable for biology students taking an overall course on evolution, and for earth science students taking one on palaeontology. In addition it will be of interest to amateur enthusiasts for fossils, evolution and natural history, all of whom will appreciate the author's lively and accessible style." I can not improve on this as a summing up.

Jane Tubb BSc Hons (Open)

Book reviews

The Geology of Cornwall by E B Selwood, E M Durran & C M Bristow (eds), 1998, University of Exeter Press, 298pp, £15.99 (paperback) ISBN 0859894320.

It's a paperback of manageable size, which is easy to read and understand. The material is well explained and is informative. There is plenty of detail on most topics and would be useful both for those who reside in Cornwall and the visitor. It seems to be reasonably priced for those visiting for a short while. It does give a list of SSSI and RIGS sites, useful for visitors.

The book has several colour plates at the beginning to whet the appetite for Cornish geology. It also has tables to explain abbreviations and chemical compounds which could be useful, and a list of the code of practice for field work which is an excellent idea.

Cornish geology is covered roughly in chronological order, as would be expected: PreDevonian, Lizard, Devonian, Carboniferous, Variscan structures, granites, mineralization, Mesozoic, Tertiary, Quaternary, but some of the chapters cover specific topics. Pages 9 to 11 give a summary of geological events in Cornwall. The text has plenty of diagrams in black and white. Each chapter is written by a different author. There is considerable emphasis on mining and mineralization. The chapter on the history of mining is rather different to the rest of the book, as it is history and economics not geology, and it is very readable. It is followed by a brief chapter on the contemporary extractive industry. The final chapter is on environmental geology which covers the impact of mining and, of course, radon produced by the granites. The book took a long time to be published and some of the authors were upset about this as they claim the data was out of date. Even so, it is a useful book for an introduction to Cornish geology.

Wendy Hamilton

Reading the Earth - Landforms in the Making by Jerome Wyckoff, 1999, Adastra West, Inc, 352pp, $29.95 (paperback), ISBN 0967407508 (available via the internet on www.mahwah.com/adastra).

You know, or soon get to know, when you begin geological studies that landforms are the result of geological processes so a good book on the subject ought to be useful to geology students. Well, this certainly is a good book and, although it is intended for general readers, it certainly would be useful to geology students. In addition, it is a nice 'casual' read, where you can dive in at any place and it also makes a useful reference work. Perhaps its best point is its massive 14 page index where underlining shows principal explanations/definitions and asterisks indicate illustrations.

To say it is lavishly illustrated is an understatement. It contains 556 photographs, mostly colour and all of good quality with many of them bled to the edge of the page, making the most of page area. There are also 75 drawings.

The first three chapters provide an overview to the origin and anatomy of the Earth, plate tectonics, volcanism, weathering, deposition, geological time etc, as well as the different types of rocks. The remaining chapters deal with the different ways that landforms are made with titles such as: sculptures by running water, features of igneous activity and works of glaciers.

Jerome Wyckoff is a well respected observer and author of things natural and this coffee table book will be enjoyed by geology students, those who enjoy landscape and many others. If, like me, you need reminding of the difference between a drumlin and an esker before you go to Symposium 2002 in 'glacial' Norfolk, it is all there, with aerial photos, on pages 259/260!

David Maddocks BSc Hons (Open), BA (Open)

Discover Dorset: Fossils by Richard Edmonds, 1999, Dovecote Press 79pp, £4.95 (paperback), ISBN 1874336652.

This book is not only a guide to collecting, but also aims to provide a background to the story fossils tell us about Dorset's past. It brought back childhood memories of holidays in Charmouth, hearing the tip-tap of hammers as I played on the beach. I remember visiting Barney's shop at the bottom of the High Street and looking in awe at the huge ammonites he had collected.

The book is set out in chapters. Edmonds starts by defining fossils, moving onto a brief outline of Dorset's geology and how fossils are useful clues to the past, then onto the fossils found in Dorset.

The descriptions of many of the fossils 'in life' are fairly clear, but I feel that more pictures would have helped novice geologists, particularly children, visualise the living organisms and their surroundings. Edmonds refers to 'distinctive' trace fossil patterns, such as the looped pattern called *Phycosyphon* pattern from the Starfish bed at Eype but, frustratingly, there is no picture of it.

I liked the description of flint formation around sponges. I can't remember having read such a clear explanation before.

Sections on 'responsible and safe collecting' and Mary Anning follow, before the author concentrates on the different areas of Dorset in more detail. Edmonds refers to many localities, and I feel it would have been useful to show these on a map to aid the many non-locals who will buy this book.

I found it difficult to visualise the sequence of beds mentioned and itched for a simplified stratigraphic column. Annoyingly the book has no index. I'm not quite sure about this book. It is written by an expert on the local geology, but I feel that he sometimes assumes too much geological and local knowledge for the potential readership of this book. However it is reasonably priced at under £5 so is worth looking at.

Sue Russell, BSc Hons (Open), PGCE

Mid Ocean Ridges, Dynamics of Processes associated with creation of new ocean crust by J R Cann, H Elderfield & A Laughton (eds), 1999, Cambridge University Press, 301pp, £55.00 (hardback) ISBN 0521585228.

Ocean floor spreading is an accepted and observed mechanism of continental drift, yet it is sometimes amazing that it is only within the last forty years that this explanation of the way that the Earth's surface was formed has been accepted. This publication is perhaps one of the most complete descriptions of the way that remote sensing technology has been used to discover what composes the solid surface of two thirds of this planet.

Drawing on borehole, seismic, satellite, magnetic and direct diving data (amongst other techniques) the editors have managed to combine a spectrum of analyses and explanations that has not before been attempted in such detail. Here indeed is the 'everything you wanted to know about mid-ocean ridges but didn't know you could ask' book. Apart from the geology, the mineralogy and the mechanisms of spreading there are also chapters on the faunal assemblage of the deep, those strange animals which survive with a completely different metabolism and energy source.

Drawing on specific points which really caught the imagination: in the chapter by Marie-Helene Cormier on the ultrafast East Pacific Rise (subject of many an S330 essay) were the discussions about the methods of large scale lateral magma transport along the line of the spreading axis and the conclusions that the upper mantle region is the preferred conduit rather than any crustal channel. This accords with the studies performed on the Oman ophiolite, which is thought to be the result of a fast-spreading ridge with similar structure.

Another subject covers the potentially economically important metalliferous sulphide deposits of the hydrothermal systems within the spreading axes. The various methods of production are discussed and examples given for the models, both current and historic. What is brought out is the sometimes episodic nature of the deposition and the potential importance of seamount caldera deposit traps, as the depth is not as great when it comes to recovering any ore materials involved. But certainly the days of readily available technology to exploit this source must be some time off.

Lastly for this review, in a highly mathematical chapter on buoyant plumes in seawater, the possible effects on weather systems or El Nino events are mentioned; the subsequent discussion covers the models need

ed to explain any phenomena observed. However, the conclusion to this chapter is inconclusive and, as the authors say, needs further study. For a general conclusion: everything is here about mid ocean ridges, and this is one to borrow from a library if you need to know.

Sandy Colby, BA Hons (Open) BSc (Open),
continuing MA Student at the University of Exeter

Fossil Crinoids by H Hess, W I Ausich, C E Brett and M J Simms, 1999, Cambridge University Press, 275pp, £45.00 (hardback) ISBN 0521450241.

A whole book devoted to Crinoids? The things called 'sea-lilies' by normal people? An obscure fossil group looking more like plants than animals, long since extinct, and of interest only to specialist palaeontologists? Wrong on all counts, as this splendid book shows!

After initial general chapters on form and function, systematics, taphonomy, ecology, etc. over 20 of the 29 chapters of this beautifully produced book are devoted to descriptions of spectacular crinoid fossil localities from Ordovician to the present, roughly half in North America, and the rest mainly in Europe.

Each of these later chapters is written by an enthusiast who has worked on 'his' crinoid assemblage, and shows that they vary enormously in shape and size. At one end there are ones small enough to go in an Open University home kit, remember *Gissocrinus* in S102/3? At the other there are crinoids with stems many metres long. They were the reef builders of their day, giving us a rock almost entirely made up of 'polo mints' of a variety of sizes. While in many places crinoids have been prepared from the surrounding rock matrix to produce the most spectacular pieces, increasingly used for decorative purposes.

The chapters are all relatively short and have the most detailed line drawings and photographs, some full page and some in colour. For the non specialist this is an ideal book for a long winter evening, where we can be taken to the authors' favourite localities and begin to share their passion for these amazingly varied and beautiful creatures.

By today's standards, this well illustrated, authoritative book, nearly 300 pages, the size of an Open University Course unit, is good value for money.

Dr Dave Williams

Majestic Universe. Views from Here to Infinity by Serge Brunnier, 1999, Cambridge University Press, 216pp, £25.00 (hardback)ISBN 0512663075.

An impressive large format book 36cms x 26cms x 3cms thick, this is principally a book of well chosen photographs, some familiar, some now over-familiar and some obscure, accompanied by essays on cosmology.

Serge Brunnier has put together an impressive collection of photographs and monographs on a variety of topics which are challenging modern cosmologists including: extra-solar planets; the "missing mass" belonging to dark matter; the convergence of particle physics with the study of the early universe; the production and recycling of elements. If that sounds daunting, don't worry. Whilst the text may strive towards the florid and poetic on occasion (though how much of that is down to the improbably named translator, Storm Dunlop, is not clear) the photographs reward study. Many have been selected from the impressive gallery collected by the Hubble Space telescope, others from leading Observatories around the world, and many were taken by Brunnier himself.

However, it will help to come to this book with some prior knowledge of astronomy and cosmology; anyone who has studied S281 will find enough to challenge them. If you haven't, don't despair; Brunnier is quite a gentle guide through some occasionally mind-bending complexities and you may find yourself motivated to tick the box beside S281 next time!

Impressive though the photographs are, the reproduction is not quite up to the standard of some recent publications, such as *Full Moon*, and that is possibly down to the price; £25 is quite cheap for a volume of this size.

There is also a fundamental problem with a book like this, on a subject of this nature where new discoveries are superseding previous knowledge on an almost monthly basis. One can go to many web sites (such as the NASA Photojournal at http://photojournal.dlr.de/ or www.space.com) and download high-quality images almost as soon as the astronomers have captured the image. It is hard to see how the lead production times of conventional publications can keep pace with the almost breakneck pace of discovery that we have seen in recent years. If books like this do have a future then it will be in the text and the ability of poets like Brunnier to place science into context, to explain the complex, inspire wonder and encourage further reading. The Bibliography, glossary and appendices are the perfect launch pad for that exploration.

Tim M Nicholls BSc (Open)

Thermal Signatures of Heat Transfer Processes in the Earth's Crust by Christoph Clauser, translated from the German original into English by Dr Clark Newcomb, 1999, Springer-Verlag, 111pp, £34.00 (paperback) ISBN 3540656049.

Lecture Notes in Earth Science: If you have NOT studied S267 and S339 then this book will be extremely heavy reading for you and you would be well advised to study the two courses first. This book is not, and I repeat not, a cure for insomniacs who have no prior knowledge of heat flow. Try reading this without the knowledge gained from S267 and S339 and you will have nightmares. That said, I found the book to be heavy reading albeit interesting – but then I have studied the aforementioned courses. The author seeks to set the scene by introducing the subject and explaining past and present precursors of thermal conditions. He then examines borehole data and questions whether the data collected are truly representative on both a local and a regional scale. He examines two cases from Bohemia and Bavaria.

The author considers two deep boreholes as case studies. The two case studies are extremely interesting. Both relate to deep boreholes; the first, KTB, was sunk in Bavaria and the second, SG-3, was sunk in the Kola Peninsular in NW Russia. At 12,261km (yes, that really is kilometres!) total depth, it is still the deepest borehole ever sunk in the world. Many people may find it difficult to accept that our world is literally afloat on a hot molten interior, even when they see volcanoes producing the evidence for them. Yet, even without volcanoes, heat is conducted from the interior to the exterior. The author has, to my mind, done an excellent job in explaining a difficult subject. The language is very technical but, unlike some publications from a far away land, this has been translated into proper English. Both the author and Dr Clark Newcomb are to be commended for this work.

The author has sought to interpret data to clarify models of the deep earth and to this end the graphics are extremely interesting, those that are in colour that is. If I have a criticism it is that of the 67 figures only 25 are in colour. I may have better colour acuity than many, but to distinguish between shades of grey! Nevertheless, for a student wishing to read further into the subject of heat flow, this book will fulfil that need. At £34.00 for some 90 pages of text, plus an appendix, references and index, to my mind it is rather expensive – but then are not all scientific books?

Gerard Vallely, continuing Earth Science student

3-D Structural Geology by Richard H Groshong Jr, 1999, Springer-Verlag, 324pp, £49.50 (hardback) ISBN 3540654224.

The subtitle "A practical guide to surface and subsurface map interpretation" is an apt description of the contents of this textbook aimed at the professional earth scientist. By constructing three-dimensional models, the interpretation and correlation of surface and sub-surface geological structures can be greatly improved, and the acquisition of 3-D modelling skills is the aim of this book. Revision of the geometry of structures present in rock formations, such as bedding relationships, folds and faults is clearly described both mathematically and by extensive use of block diagrams, cross sections, and contour maps.

The reader is guided through the methods and techniques of constructing a three-dimensional model from a two-dimensional geological map, by fully illustrated worked examples. Problems encountered and assumptions made are fully discussed. The importance of making accurate cross

sections and of contouring is stressed; for example, differing contouring will result in a change of shape for the same rock formation.

By following the author's detailed instructions it is relatively easy to construct a three-dimensional model by hand, ie. using 'pencil, paper, and calculator' - an eraser is also useful! Such models are extremely useful in deciding the shape of the structure. Also comparison with the rock formation as seen in the field can be made. However, more complicated techniques require intensive calculations, especially when correlating surface and sub-surface structures from maps, seismic profiles and well logs, and thus are better performed using computer software. These techniques are fully described, all equations are defined at the end of the relevant chapters.

The final two chapters describe the techniques for validating and restoring three-dimensional models, both important in assessing the accuracy of the model.

Throughout the book the reader is encouraged to solve the problems set at the end of each chapter (with the exception of chapter 1). The reader must validate the solution reached. This is a very useful book which can help considerably in the development of three-dimensional modelling skills. References cited in the text are recorded at the end of the relevant chapters.

Muriel Wright BA Hons (Open)

Principles of Sedimentary Basin Analysis, 3rd Edition by Professor Andrew D Miall (University of Toronto), 1999, Springer-Verlag, 616pp, £51.50 (hardback) ISBN 3540657908.

Précis: A comprehensive if somewhat technical work which, whilst laying down guidelines for the methodology of research into sedimentary geology, also provides a broad grounding in the physical processes, geological structures and theoretical models in use today.

Review: This book may contain far more than the lay reader may care to know about Sedimentary Basin Analysis. It is aimed squarely at undergraduates wishing to pursue a career in geology, particularly the "soft rock" side. To this aim it covers the processes of sedimentary deposition, stratigraphy, facies models and analysis, mapping methods and sequence stratigraphy, before going on to look at the influence of regional and global cycles and the influence of plate tectonics on sedimentation. The text also lays down the methodology that Professor Miall believes to be appropriate for research and the production of reports and papers.

Readers, who have studied S338, will find that it covers all the material from both the Tucker and Walker set books. (Miall contributed a chapter on Alluvial Deposition to "Facies Models" by R G Walker). The work builds from examining small-scale structures through facies modelling to examine some case studies of some major sedimentary basins. Indeed, were I on the course team preparing the successor to S338, I would propose this tome as a replacement for all three set books, the price notwithstanding.

One need not begin this book with much prior knowledge of sedimentary geology because Professor Miall does not overlook the basics. There are details on how to draw stratigraphic logs, tables of grain sizes, explanations of the techniques of petrophysical logging as used to examine bore-holes and wells. What one needs to finish the book, though, is a deep interest in sedimentary geology and not a little perseverance. There are many well chosen (black and white) photographs and illustrations. The style of the illustrations may look to modern eyes somewhat "old fashioned", accustomed as we now are to the clean lines of computer-drawn graphics. However, this is a result of culling many of the illustrations from other papers and publications. As befits a serious academic tome there are copious references at the end of each chapter and an excellent index by author and subject.

Tim M Nicholls BSc (Open)

The Stratosphere - Phenomena, History and Relevance by Karin G. Labitzke & Harry Von Loon, 1999, Springer-Verlag, 178pp, £37.50 (hardback) ISBN 3540657843.

The book begins with the unexpected discovery in 1901 of the stratosphere by Assmann and Teisserenc de Bort when they identified the temperature inversion which defines the stratosphere. Until then it had been assumed that temperature increased with altitude until at some undefined point absolute zero would be reached. The descriptions of the hardships they endured (like all early adventurers) and the photographs of the balloons they used to reach literally new heights are fascinating, as are the endeavours of all pioneers of the science that we take so much for granted today. The second chapter reviews the average conditions in the stratosphere, particularly highlighting differences between the hemispheres and looks at the reasons for fluctuations in the height of the tropopause, the base of the stratosphere, and the depth of the stratosphere itself above different parts of the globe and in different seasons.

Chapter 3 looks at interannual variability in the Northern Hemisphere's stratosphere including wave propagation from the troposphere and the effects of solar and volcanic activity and considers the difficulty of getting measurements, even today, especially regarding comparative effects in and due to the troposphere. A comparison of Arctic and Antarctic winters and the effect of the proximity of the oceans to the North Pole (compared with Antarctica) on the formation of the Arctic ozone hole leads to discussion of the Ozone Layer in Chapter 5, which starts with a discussion of ozone depletion from a meteorological point of view and goes on to explain the development of knowledge since the 1930's. Chapter 4 is devoted to a description of the Quasi-Biennial Oscillation in the equatorial stratosphere and reviews evidence for a similar oscillation in the troposphere over the last 100 years.

The preface states that the book is for meteorologists and other scientists as well as for general readers who do not want to refer to academic texts. The book fell somewhere between a basic academic textbook and a popular science book and I found myself delving into what I had learned in S330 Oceanography, without which I may not have kept up with what was written.

It is generously illustrated with tables, charts and maps which well reinforce the message of the text. I enjoyed it very much but at nearly forty quid I don't feel the need to have my own copy at home.

Chris Crivelli BSc(Open) continuing
Environmental Science student

Volcanoes in the Quaternary by C R Firth & W J Mcguire (eds), 1999, The Geological Society Special Publication No. 161, 232pp, £65 (hardback) ISBN 1862390495.

This book contains a collection of 13 papers that together form a representative cross-section of research into the Quaternary volcanic activity and the Quaternary glaciations and their environmental impact.

The papers have been grouped on a geographical basis: the first 3 are associated with the volcanic province of New Zealand's North Island, a further 3 papers relate to the East African Rift Valley and the Mediterranean and the following 5 papers deal with Late Quaternary eruptions in Iceland. The last 2 papers are conducted on Atlantic volcanic islands and provide detailed study of the hazards expected in such areas.

The collective papers cover the determination of eruptive chronologies, they discuss the impact of volcanic eruptions and the associated fall-out of tephra on local and regional vegetation and the important causal variables (e.g. weather, pre-existing hydrological conditions and the population actually present). They stress the importance of tephrostratigraphic records and look at the regional impacts of eruptions ending with assessments of modern volcanic hazards.

This book is not a bedtime reading book, although some of the papers are a pleasure to read and are understandable especially for those students who are just beginning their studies. However, several papers are rather technical and can prove heavy reading unless one has a particular interest in the subject matter.

There are 232 pages, 75 illustrations plus an index and although it is a very interesting book, it is rather specialised which is reflected in the price of £65.00.

Margaret Bemrose BSc Hons (Open)

THE NATIONAL CONSTITUTION OF THE OPEN UNIVERSITY GEOLOGICAL SOCIETY

1 NAME

1.1 The Society shall be known as the Open University Geological Society herein after referred to as The Society.

2 AIM

2.1 To promote and advance public education in the field of geology and other earth sciences. In furtherance of that object but not further or otherwise The Society shall have the power to do all or any of the following:-
(i) Promote and support local branches of The Society.
(ii) Organise symposia, conferences, national and local events.
(iii) Provide a means by which members receive information on the activities of The Society and on earth sciences.
(iv) Foster good relations with organisations having related interests.
(v) Raise funds.

3 MEMBERSHIP

3.1 Full Membership shall be open to:
i) past and present students of The Open University.
ii) academic, research, technical, tutorial and counselling, and administrative staff of The Open University.

3.2 Associate Membership shall be open to any adult person (i.e. aged sixteen or over).

3.3 Family Membership shall be open to any other named adult residing at the same address as a full member.

3.4 Temporary Membership shall be open to any adult person and shall be valid only for the duration of the event in which the temporary member is participating.

3.5 Joint membership shall be open to two full members residing at the same address at an appropriate subscription.

3.6 A member in any of the above categories shall be defined as one who has paid a current and appropriate fee.

3.7 The President and Past Presidents shall be deemed members for life of The Society and shall not be required to pay any subscription.

3.8 Honorary Life Membership may be conferred by a general meeting of The Society following recommendation by the National Committee, to which body ordinary members may make recommendation.

4 SUBSCRIPTIONS AND FINANCE

4.1 The Society's year shall run from 1st January to 31st December.

4.2 The annual subscription and temporary membership fees shall be decided at the preceding Annual General Meeting. The annual subscription shall become due on the first day of the Society's year.

4.3 Subscriptions received from members joining for the first time on or after 1st July will extend over that year and the whole of the following year.

4.4 If a subscription has not been renewed by 31st March, membership shall be deemed to have lapsed.

4.5 Any member acting on behalf of The Society shall keep a record of income and expenditure incurred.

4.6 The accounts of The Society shall be subject to annual audit. Audited annual accounts shall be presented by the National Treasurer to the National Committee, to the Open University Students Association (OUSA) and to the next Annual General Meeting of the Society. Copies of the audited accounts shall be distributed to members not later than one month before the Annual General Meeting.
A member may request a copy of the accounts after audit has been announced in the National Newsletter.
The auditor(s) for the next financial year shall be appointed at the Annual General Meeting.

4.7 The National Treasurer shall present a statement to the Annual General Meeting on the current financial situation of The Society and a forecast for the coming year.

4.8 Fund raising shall be subject to the approval of the National Committee.

4.9 Any university, library, organisation or society may receive any publication of The Society by payment of a fee equivalent to the current membership fee or in exchange for some similar publication.

4.10 Members of The Society may be reimbursed for any expenses incurred on behalf of The Society, but shall receive no fee.

5 GOVERNMENT

5.1 The National Executive shall be responsible for the management of The Society.
The National Committee shall be responsible for overall policy and for the activities of The Society's Branches.
Members of the National Committee may act individually or collectively to deal with routine matters.

5.2 The National Executive shall consist of the following:-
The President
The Chairman
The Secretary
The Treasurer
The Membership Secretary
The Newsletter Editor
The Information Officer
The Events Officer
plus a Branch Organiser (elected annually in March or April by the Branch Organisers).

5.3 (i) The National Committee shall consist of the following:-
The members of the National Executive
The Branch Organisers
The Sales Officer
All members of the National Committee must be Full Members of The Society at the time of their election and for the duration of their term of office.
At least one member of the National Committee shall be a current student of the Open University.
(ii) The Society's Representative or Deputy Representative to OUSA shall be entitled to attend meetings of the National Committee, but shall not have voting rights at such meetings.

5.4 The National Executive may co-opt the following post-holders:-
- a Minutes Secretary for each national meeting
- a Journal Editor
- an Administrative Assistant
- a Covenants Secretary
- the Symposium Organiser(s)
- such other assistants as may prove necessary

These post-holders may attend National Executive and National Committee meetings as appropriate, but shall not have voting rights at such meetings.

5.5 (i) No one person shall hold two or more National posts concurrently.
(ii) No one person shall hold two or more National Executive posts consecutively. Election to the position of Chairman of The Society shall be an exception.

5.6 The National Committee shall invite a member of the academic staff of the Earth Sciences Department of the Open University to be President of the Society for a term of two years, commencing in even-numbered years.

5.7 The Society through its National Committee shall be empowered in exceptional circumstances to offer a position of Vice-President.

6 PROCEDURE

6.1 There shall be an Annual General Meeting (AGM).

6.2 A Special General Meeting may be called at the request of the National Committee, any three branches, or fifty full members. The motion(s) to be debated at the meeting must be specified in writing at the time the request is submitted to the National Secretary.

6.3 General Meetings shall be conducted according to the Standing Orders for General Meetings.

6.4 The National Secretary shall give fourteen weeks notice in writing to all members of the date, time and venue of any National General Meeting. National General Meetings shall be held at weekends or on public holidays.

6.5 (i) Any member shall give the National Secretary at least twelve weeks written notice of any constitutional motion to be placed on the agenda of the Annual General Meeting.
(ii) Any member shall give the National Secretary at least four weeks notice of any non-constitutional motion to be placed on the agenda of the Annual General Meeting.
(iii) Other matters may be placed on the agenda of any National General Meeting subject to the approval of the National Executive.

6.6 The National Secretary shall send the agenda for National General Meetings to all members at least two weeks before the meeting.

6.7 Nomination for election as Officers of The Society should reach the National Secretary at least two weeks before the appropriate AGM. Nominations shall be in writing, with written permission of the nominee and endorsed by two Full Members of The Society.

6.8 Membership of The Society must be proved to gain entry to General Meetings.

6.9 Full Members may speak on motions at General Meetings and may vote. Associate and Family Members may speak on motions at General Meetings but may not vote.

6.10 Members of the National Committee shall submit their resignations at the appropriate AGM, but may be eligible for re-election.

6.11 (i) National Committee Members other than Branch Organisers shall serve for a term of two years, with a maximum of six years and six months in the same post.
(ii) National Committee Members other than The President and The Chairman shall be elected at the appropriate AGM.

(iii) The Society's Representative and Deputy Representative to OUSA shall be elected at the appropriate Annual General Meeting, each to serve for a term of two years.

6.12 The Secretary, the Membership Secretary, the Information Officer and the Society's Representative to OUSA shall be elected at the Annual General Meeting in even-numbered years.
The Treasurer, the Newsletter Editor, the Events Officer, the Sales Officer and the Deputy Representative to OUSA shall be elected at the Annual General Meeting in odd-numbered years.
Individual elections to be in the order given above.

6.13 (i) The Chairman of The Society shall be elected by the National Committee from amongst members who have served on the National Committee for a term of office during the previous five years. The election shall take place in odd-numbered years.
(ii) Nominations for the post of Chairman of The Society shall be made in writing by members of the National Committee, to the National Secretary at least two weeks before the meeting of the National Committee at which the election of the Chairman is to be held.
(iii) When a vacancy occurs by resignation, disqualification or death of the Chairman of The Society, a new Chairman shall be elected at the next National Committee Meeting, pending which the National Secretary shall assume the responsibilities of the Chairman.

6.14 Members of the National Committee, other than the President, the Chairman and Branch Organisers, shall be elected by single transferable vote of Full Members present at a General Meeting of The Society.

6.15 When a vacancy occurs by reason of resignation, disqualification or death a replacement shall be appointed by the National Executive to fill the vacancy until the next General Meeting, when the replacement shall retire, but may stand for election for the next or remaining term of office.

6.16 The Society's Constitution may only be amended at the National Annual General Meeting or at a Special General Meeting called for the purpose. A two-thirds majority of those present and voting is required for such amendments. No alteration may be made to the Constitution(s) which would cause the Society to cease to be a Charity at Law.

6.17 All other voting decisions shall be by simple majority.

6.18 The Society may be dissolved by consent of two-thirds of those present and voting at a Special General Meeting called for that purpose. If upon winding up there remains after the satisfaction of all debts and liabilities any funds whatsoever the same shall not be paid or distributed amongst the Members of the Society but transferred to some other society or societies having objects similar to those of The Society and if and so far as effect cannot be given such provision then to some charitable object, that shall include OUSET (Open University Students Educational Trust).

7 BUSINESS

7.1 The National Committee shall meet at least twice a year, once immediately before the AGM.

7.2 A quorum of eight, five of whom must be Branch Organisers, shall be required at a National Committee Meeting with at least one of the following present: Chairman, Secretary or Treasurer. A quorum of four shall be required for a National Executive Meeting with at least one of the following, Chairman, Secretary or Treasurer.

7.3 The National Committee shall be empowered to appoint Special Committees whose objectives and reporting dates shall be defined in writing by the National Committee. All members of The Society shall be informed of the formation and objectives of any such committee at least fourteen days before the reporting date.

7.4 Minutes shall be taken of all National Executive and National Committee Meetings and copies circulated to National Committee Members.

7.5 The minutes of any National General Meeting shall be published in the next possible national newsletter of The Society after the meeting to which they refer.

7.6 The National Committee shall maintain Guidelines for the operation of The Society. Such Guidelines shall be available to members of The Society.

8 LIMITATIONS

8.1 The name or any logo of The Society may not be used without the permission of the National Executive.

8.2 The Society cannot accept liability for the costs of any damages, fire, theft, legal fees or injury incurred by the activities of individual members.

8.3 The National Committee shall have the right to suspend or expel any Officer, National Committee Member, Full, Associate or Family Member acting against the aims of the Society after full consideration of the case. The member shall have the right to present a case, or a subsequent appeal, to the Committee either orally or in writing. The case or appeal may be presented by any person of the member's choice. Any member so treated shall have the right to appeal to The Society at the AGM following.

8.4 The National Committee reserves the right to refuse admission to any applicant for membership who they have reason to believe is unsympathetic to any of the aims of The Society or the interests of its members or is liable to bring The Society's good name into disrepute. Any such person refused membership shall have the right to make representation orally and/or in writing and to be represented by any other person of their choice. Anyone refused membership by the National Committee may appeal against the decision to the President of The Society.

9 INTERPRETATION

9.1 Any matter of doubtful interpretation, or not provided for in the Constitution shall be dealt with by The National Executive pending endorsement or otherwise at the next General Meeting.

As amended at the AGM of the Society 25 November 2000.

BRANCH CONSTITUTION

This Branch Constitution will be used in conjunction with the National Constitution of the Open University Geological Society

1 NAME

1.1 The Organisation shall be called the ..... Branch of the Open University Geological Society.

2 AIMS

2.1 (i) To further the objects of The Society in advancing education.
(ii) To provide a local means for forwarding the aim of the Society.

3 MEMBERSHIP

3.1 Membership shall be open to all members of The Society who are best served by the ..... Branch, or who have chosen to be allocated to that Branch.

4 FINANCE

4.1 Any Branch Member shall ensure a record is kept of any monies expended or received on behalf of the Branch.

4.2 The Branch Treasurer shall present audited accounts to the Branch AGM. A copy of these accounts must be sent to the National Treasurer within four weeks of audit.

4.3 The Branch shall have the power to raise funds from any sources approved by the National Executive.

5 GOVERNMENT

5.1 The Committee shall consist of:-
- the Branch Organiser
- the Branch Treasurer
- other Committee Members, one or more, as required

5.2 The Branch Organiser, the Branch Treasurer and at least one other Committee Member must be Full members of The Society at the time of their election and for the duration of their term of office.

5.3 (i) No member shall hold any other National post at the same time as that of Branch Organiser.
(ii) No member shall hold the post of Branch Treasurer at the same time as that of National Treasurer.

5.4 The Branch Organiser shall represent the Branch at The Society's National Committee or, if absent, must nominate a Branch Committee member as deputy who shall not otherwise be a member of the National Committee.

6 PROCEDURE

6.1 There shall be a Branch Annual General Meeting. Minutes must be kept and a copy sent to the National Secretary and the National Treasurer within four weeks. (NB Branch Grants may not be paid if this and 4.2 are not complied with).

6.2 Branch General Meetings shall be conducted in accordance with Standing Orders for General Meetings Addenda 1.

6.3 The Branch Organiser shall ensure a minimum of four weeks notice in writing is given to Branch Members and the National Secretary of the date and time and venue of the Branch AGM.

6.4 All members of the Branch Committee shall retire at the Branch AGM but be eligible for re-election.

6.5 A special Branch General Meeting may be called at the request of 10% of the members, or five members, whichever is the greater, or by the Branch Committee or by the Branch Organiser.

6.6 Within two weeks of receipt of notice of a request for a Special Branch General Meeting, the Branch Organiser shall give not less than three and not more than five weeks notice in writing of the agenda to all Branch Members, and to the National Secretary, giving the date, time and venue of the meeting.

6.7 Every field trip, lecture or other gathering shall be considered a Branch Meeting.

6.8 In the absence of the Branch Organiser, a Chairman shall be elected from among the members present at a Branch Meeting if business is to be con-

ducted formally.

6.9 A Branch Constitution may only be amended with the approval of the National Committee before being amended formally at the next General Meeting of the Society. No alteration may be made to the Branch Constitution which would cause The Society to cease to be a Charity at law.

DISSOLUTION CLAUSE

If upon dissolution there remains after satisfaction of all debts and liabilities any assets whatsoever the same shall be given to the Open University Geological Society or if that body has already been dissolved then to some charitable object which shall include OUSET.

As amended at the AGM of The Society 13 November 1999.

STANDING ORDERS FOR GENERAL MEETINGS OF THE OPEN UNIVERSITY GEOLOGICAL SOCIETY

1 QUORUM

a) A quorum of twenty five Full Members shall be required of whom at least ten shall not be National Committee members.
b) If a quorum is not present within one hour after the time appointed for the meeting to commence, the meeting shall be dissolved.

2 AGENDA

a) The agenda shall be prepared by the Chairman and the National Secretary.
b) Items not on the agenda may be introduced for consideration after business on the agenda has been completed.

3 THE CHAIR

a) The Chairman of The Society shall take the Chair.
b) If the Chairman is absent the President of The Society or another member of the National Executive shall deputise.
c) The Chairman shall be responsible for the conduct of the meeting.
d) All business shall be addressed to the Chair.
e) Should the Chairman wish to participate in a debate, the Chair shall be surrendered to the President or other agreed deputy for the duration of that debate. The person occupying the Chair may not participate in any debate.
f) The Chairman may call attention to irrelevance, repetition, unbecoming languague or any breach of order on the part of a member, and may direct the member to discontinue. In the event of persistent disregard for the authority of the Chair, the member shall retire for the remainder of the meeting.
g) The Chairman's decision on the interpretation of the Standing Orders, and on any point of order not provided for by the Standing Orders, shall be final.

4 RULES OF DEBATE

a) The Chairman shall decide the right of priority in speaking.
b) No speech shall occupy more than three minutes without the consent of the meeting.
c) A motion or amendment shall be proposed and seconded by a full member.
d) The proposer shall have first speech, after which the motion or amendment shall be open for debate.
e) No member except the proposer may address the meeting more than once on any one motion.
f) Once open for discussion a motion may only be withdrawn with the consent of the meeting.
g) The proposer of the motion shall have the right to sum up on the debate immediately before the vote is taken. The proposer may waive the right absolutely or in favour of another person.
h) No new information shall be introduced after the summing up has begun.
i) There shall be only one motion or amendment before the meeting at any one time.
j) Amendments to any matter on the agenda may be accepted up to the commencement of the meeting, subject to (c) above, or at the discretion of the Chairman.
k) No member may move more than one amendment to any motion.

5 VOTING

a) Each Full Member present excluding the Chairman shall have one vote.
b) The Chairman shall have a casting vote in the event of a tie.
c) Except for elections, voting shall be by a show of hands unless five Full Members request a ballot.
d) For a motion to succeed, a simple majority shall be required, except that any motion to amend the Constitution, Branch Constitution or Standing Orders shall require a two-thirds majority.

6 ELECTIONS

a) The system of the Single Transferable Vote for the election of members of the National Executive and the National Committee is defined as follows:-

(i) All electors shall mark their ballot papers with their ordered preferences for the allocation of their vote to one or more candidates.

(ii) On the first count candidates shall be allocated the first preference votes on the ballot papers.

(iii) At each count the votes allocated to each remaining candidate shall be counted.

(iv) After each count the candidate allocated the least num ber of votes shall be eliminated from the election. The votes cast for the eliminated candidate shall be re-allocated to the remaining candidates according to the next preferences marked on the ballot papers.

(v) The counts shall cease when the total votes allocated to one candidate constitute an absolute majority of the total votes cast. The candidate with the absolute majority shall be declared elected.

7 PROCEDURAL MOTIONS

a) Procedural motions shall have a proposer and seconder.
b) Procedural motions shall not be proposed while a member is speaking on a point of order or information or during the taking of a vote.
c) The following Procedural motions may be put to the meeting without discussion:-

- that the motion be now put
- that the motion be not put
- that the motion or amendment be voted on in parts
- that Standing Orders be suspended (which requires a two-thirds majority)
- that the meeting be closed

d) The following Procedural Motions may be put with only one speech for and one against:-

- that the matter lie on the table
- that the matter be referred to the National Executive
- that the matter be referred to the National Committee
- that the matter be referred to a Special Committee for investigation or re-examination
- that the meeting be adjourned temporarily
- a challenge to the Chairman's ruling (which shall require a two thirds majority)

8 GENERAL RULES

a) No question once decided may be re-opened at the same meeting.
b) Any suspension of the Standing Orders shall only apply for the duration of the matter under discussion.
c) If an amendment is accepted by the proposer of the motion then the motion remains with the proposer. If it is not accepted by the proposer, but is then carried, the amended motion becomes the property of the proposer of the amendment.
d) Amendments tabled second and subsequent to a motion may fall if the first amendment is carried or accepted. The Chairman shall rule on this.
e) Points of information may be raised by any member.
f) Points of order may be raised by any member. They have precedence over all other business except the taking of a vote unless they concern the conduct of the vote. They must be framed as a question to the Chairman and shall be related only to the conduct of the meeting.

ADDENDA 1

1 These Standing Orders shall apply to Branch Meetings of the Open University Geological Society.

2 Branch General Meetings shall be conducted according to Standing Orders for General Meetings, subject to the following amendments:-
i) 1(a) shall be replaced by "*A quorum of 5% of the Branch members or five members, whichever is the greater, shall be required.*"
ii) 2(a) shall be replaced by "*The agenda shall be prepared by the Branch Organiser.*"
iii) 3(a) shall be replaced by "*The Branch Organiser shall take the Chair.*"
iv) 3(b) shall be replaced by "*If the Branch Organiser is absent another member of the Branch Committee shall deputise as Chairman*."
v) 3(e) Delete "*the President or other*" and replace with "*an*"
vi) 5(c) Delete "*Except for elections*"
vii) 5(d) Delete "*Constitution,*" and "*or Standing Orders*"
viii) 7(d) Add "*that the matter be referred to the Branch Committee when the meeting in question is a Branch General Meeting*"

As amended at the AGM of The Society 13 November 1999